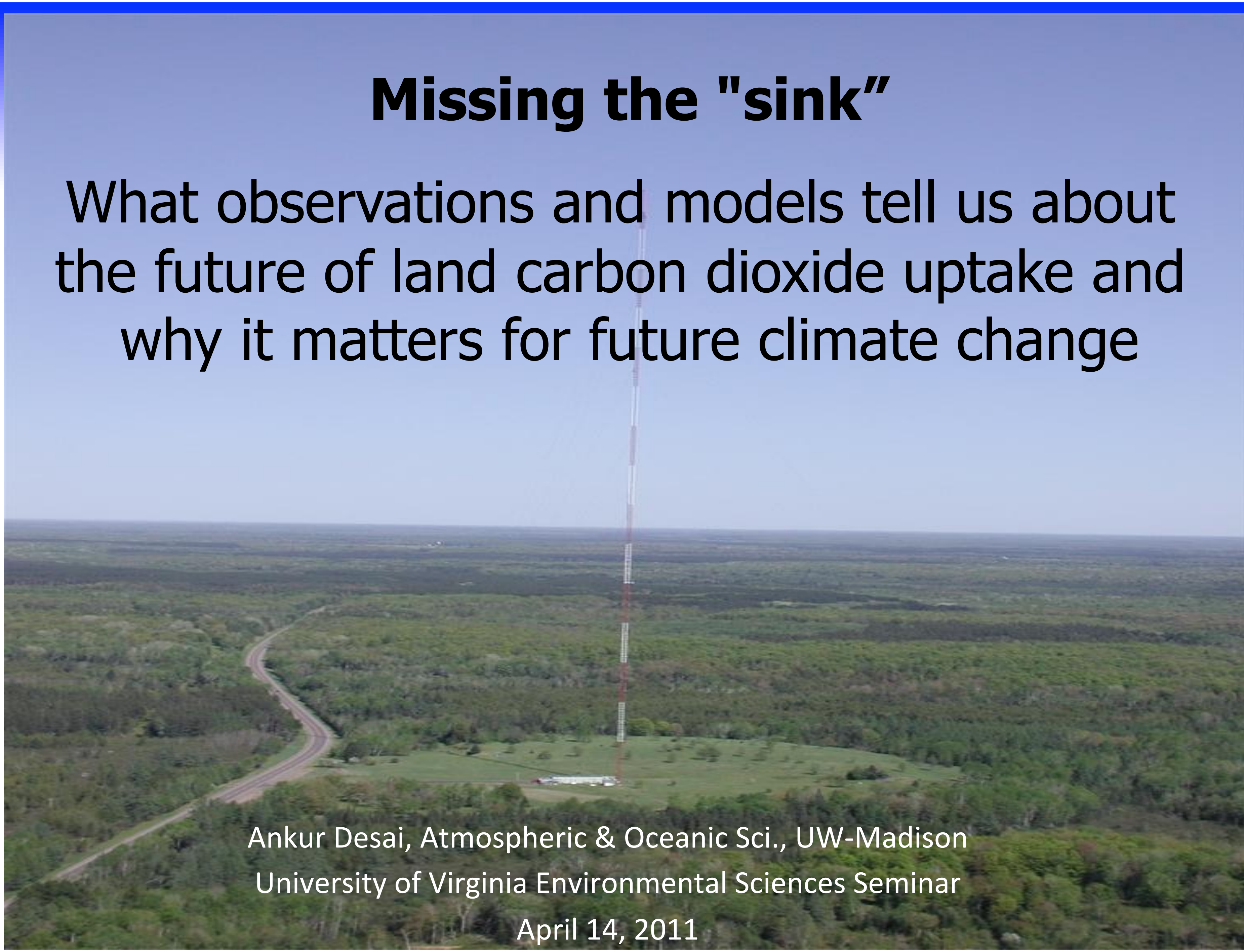
Missing the "sink"

What observations and models tell us about the future of land carbon dioxide uptake and why it matters for future climate change



Ankur Desai, Atmospheric & Oceanic Sci., UW-Madison

University of Virginia Environmental Sciences Seminar

April 14, 2011

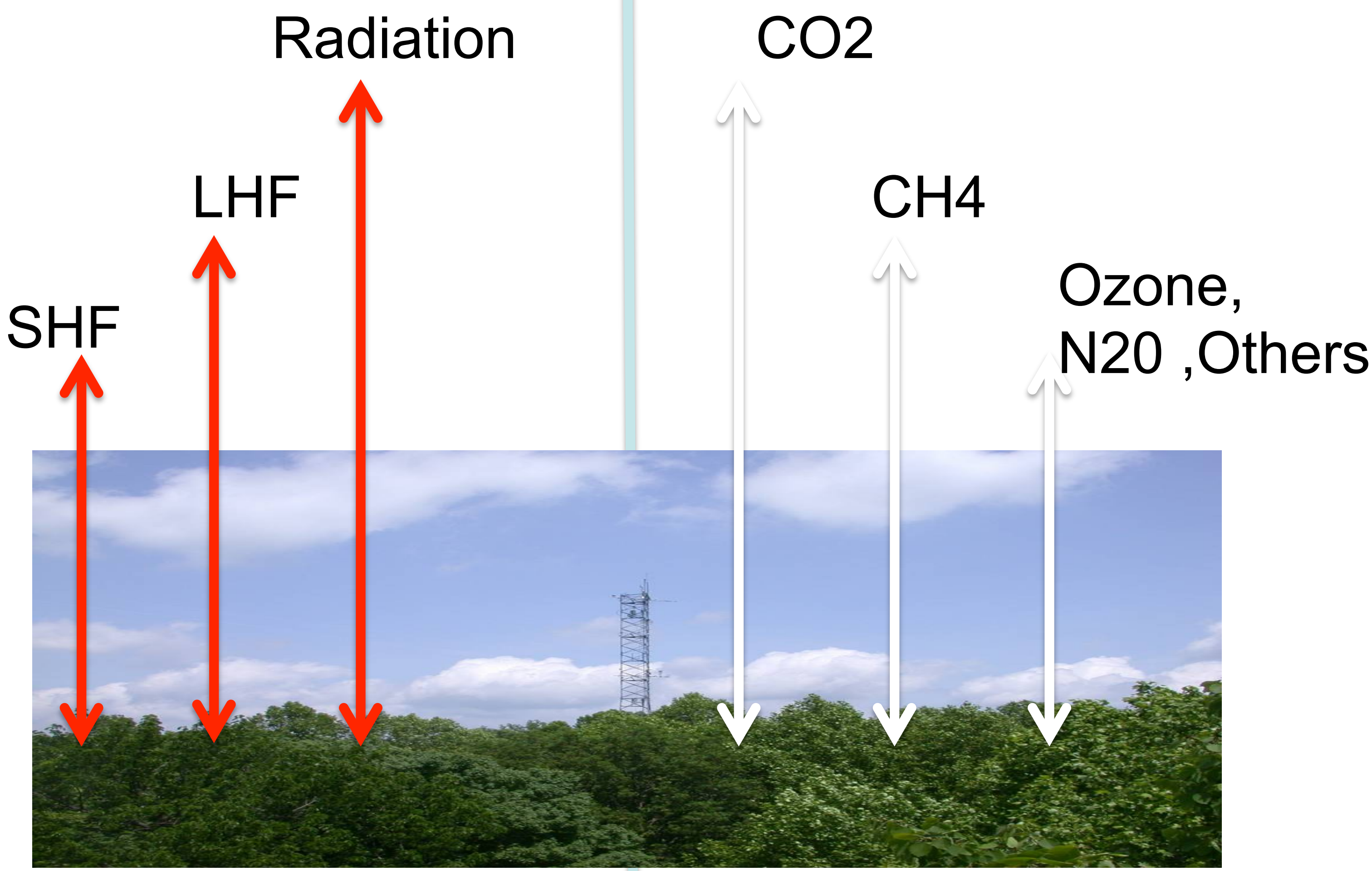
Forests in the Earth System

- Climate system is driven by
  - Forcings that impact the energy budget, water cycle, or trace gas and aerosol composition of atmosphere
  - Feedbacks that reverse, limit, or enhance these forcings
- Forests have low albedo, moderate evapotranspiration rates, and high carbon stores. They also cover a significant area of the global land surface
  - Consequently, forcings and feedbacks imposed by forests are worth considering!

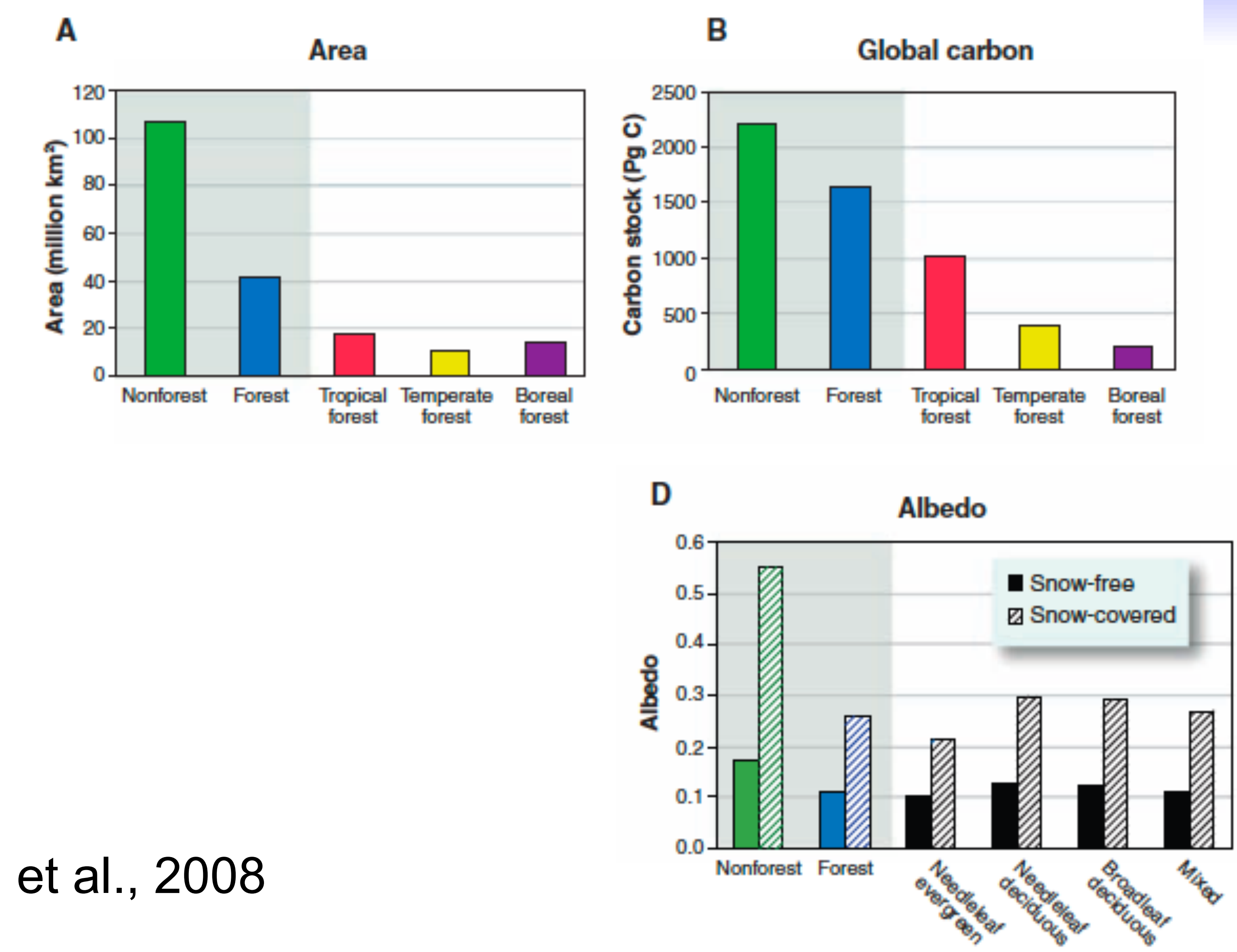
Forests in the Earth System

<u>Biogeophysical Mechanisms</u>

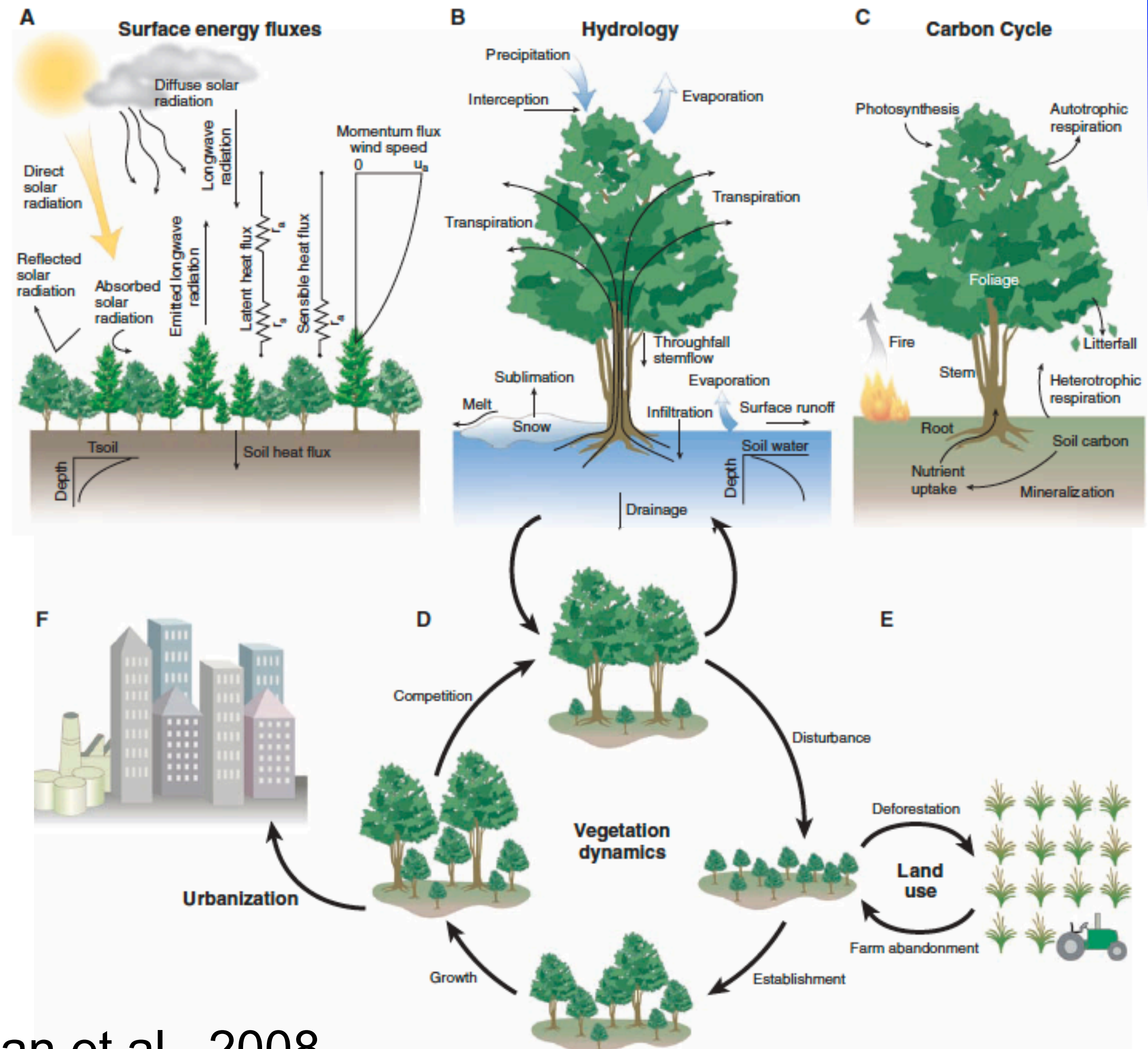
<u>Biogeochemical Mechanisms</u>



Forests in the Earth System



Bonan et al., 2008

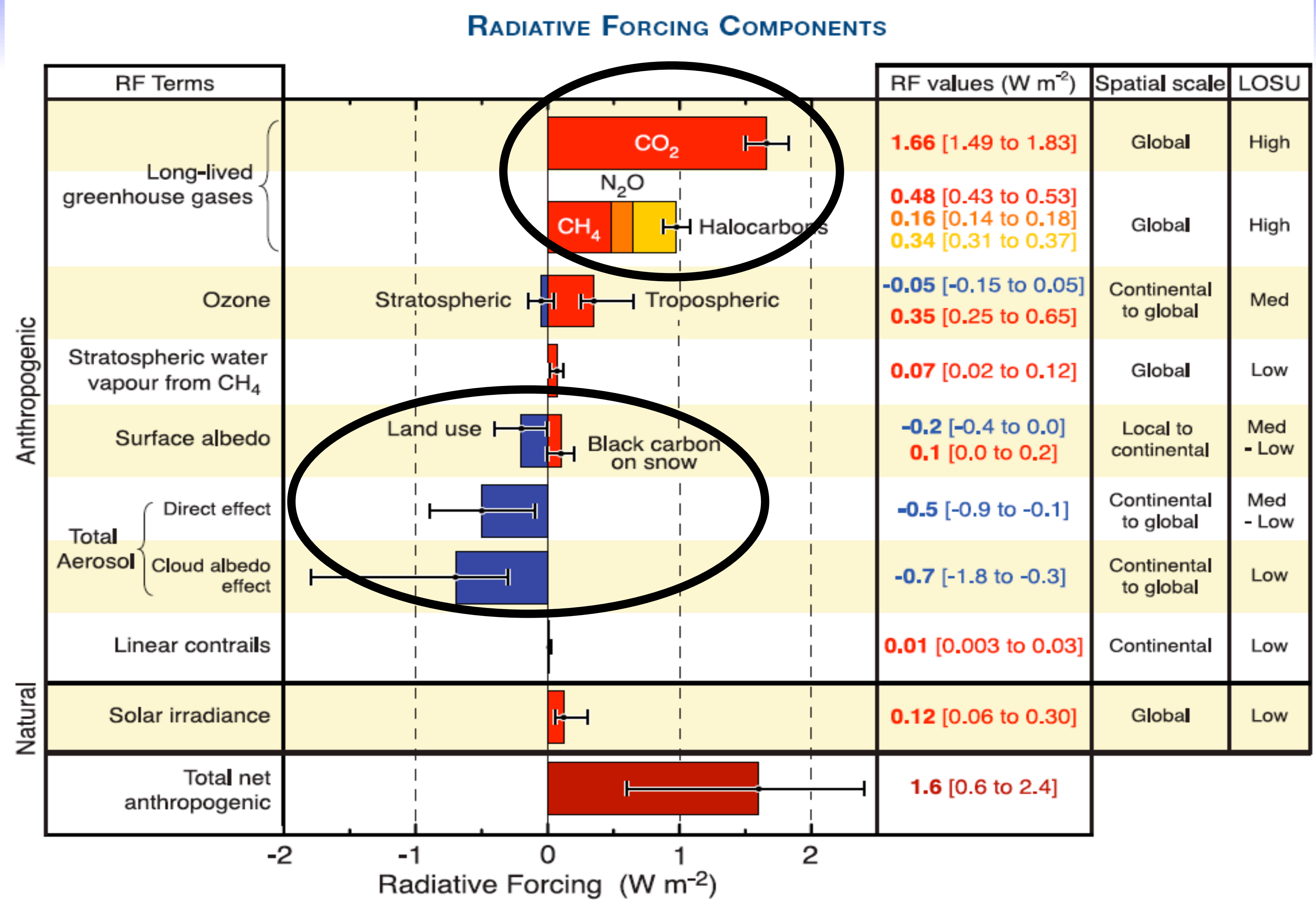


Bonan et al., 2008

Hypothesis

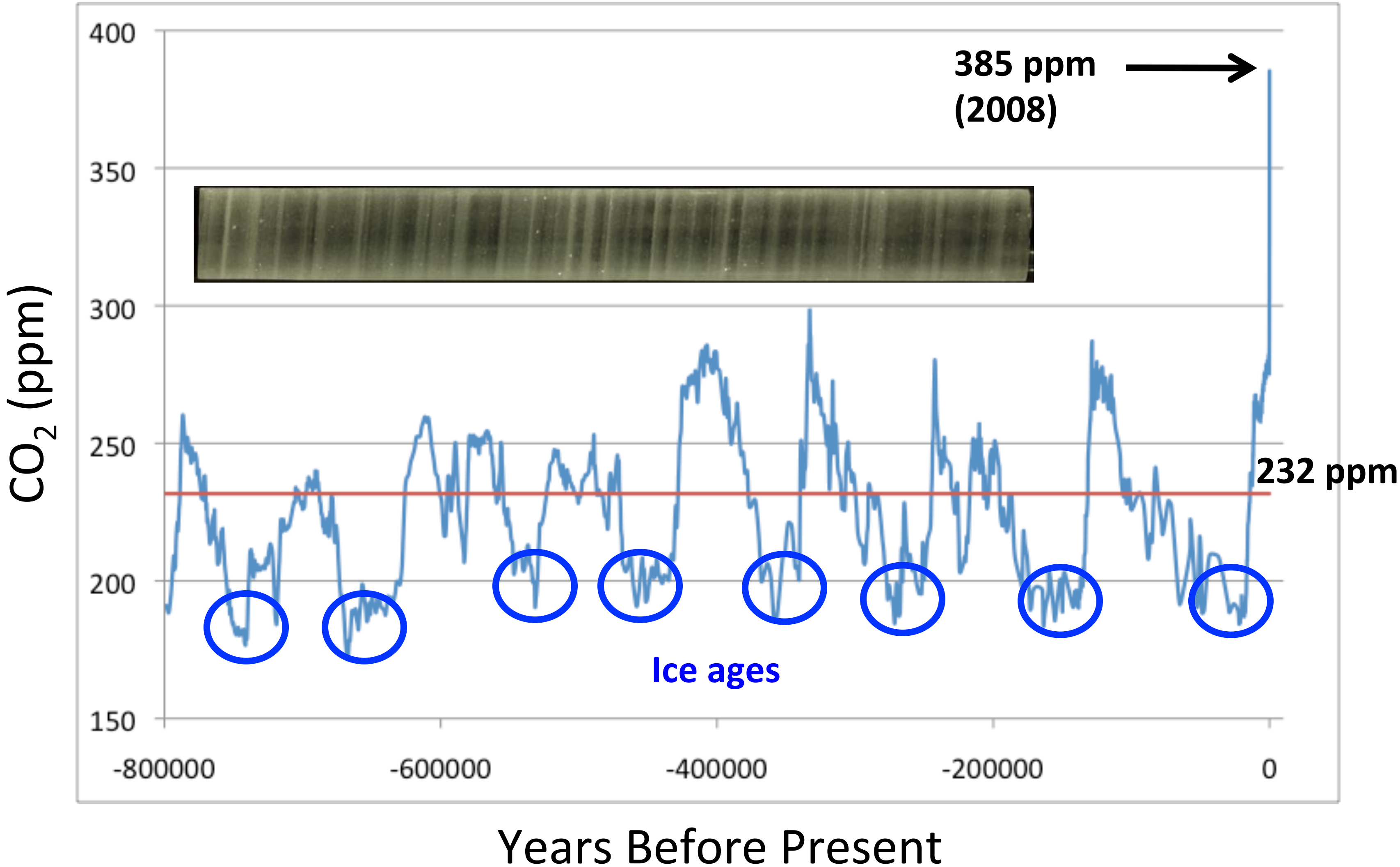
- The indirect sensitivity and feedbacks of forest carbon cycle to climate change may dwarf the direct sensitivity
  - Direct effects
  - Indirect effects
- Contemporary observations of forest carbon exchange can be used to evaluate and improve predictive simulation models

What Do We Know?



IPCC, 4th AR, (2007)

What Do We Know?



Source: Lüthi et al (2008), CDIAC, & Wikimedia Commons

What Do We Know?

Since 1990:

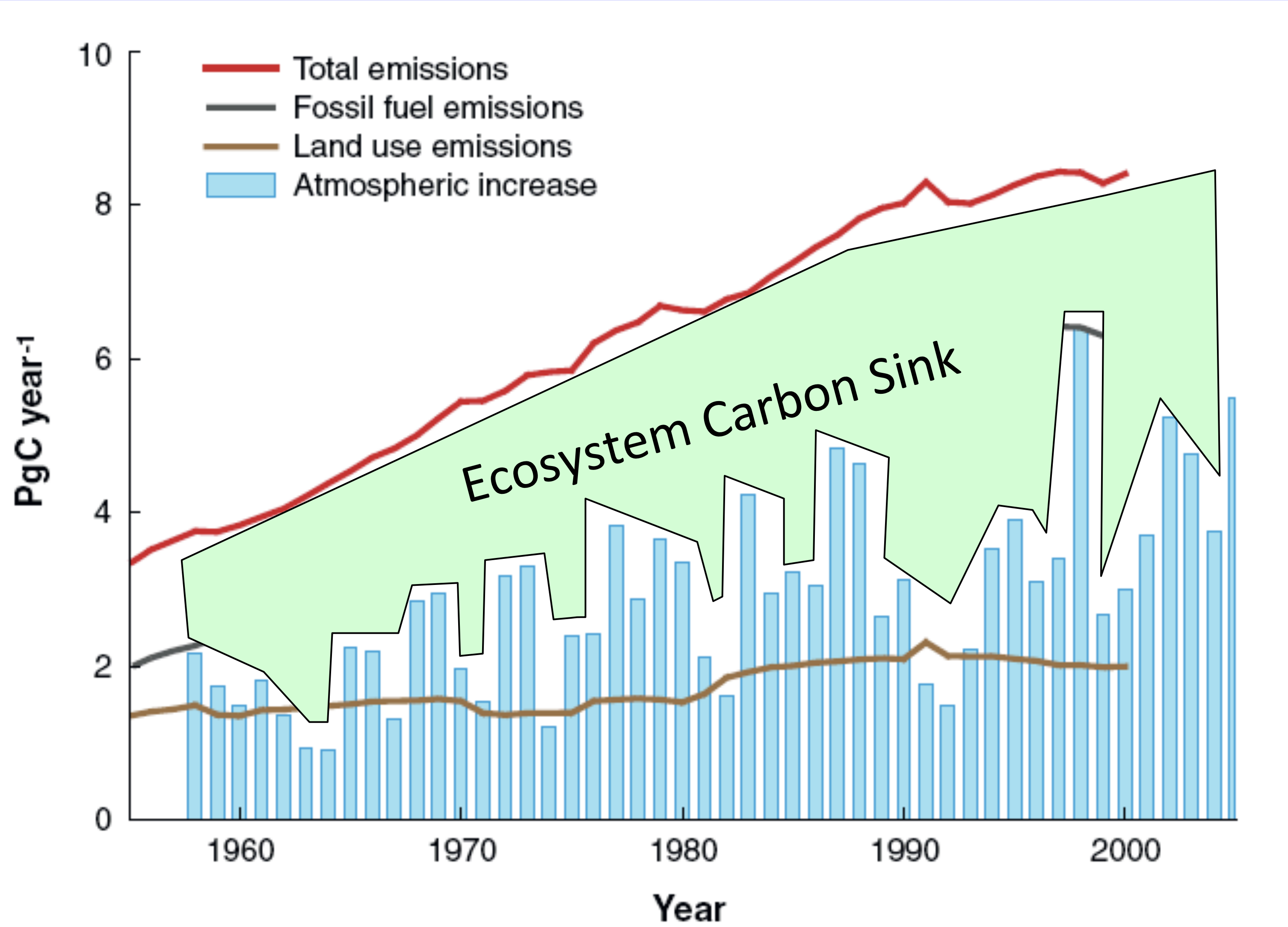
- Global annual CO_2 **emissions** grew 25% to
  27,000,000,000 tons of CO_2

- CO_2 in the **atmosphere** grew 10% to
  385 ppm

- At current rates, CO_2 is likely to **exceed**
  500-950 ppm sometime this century

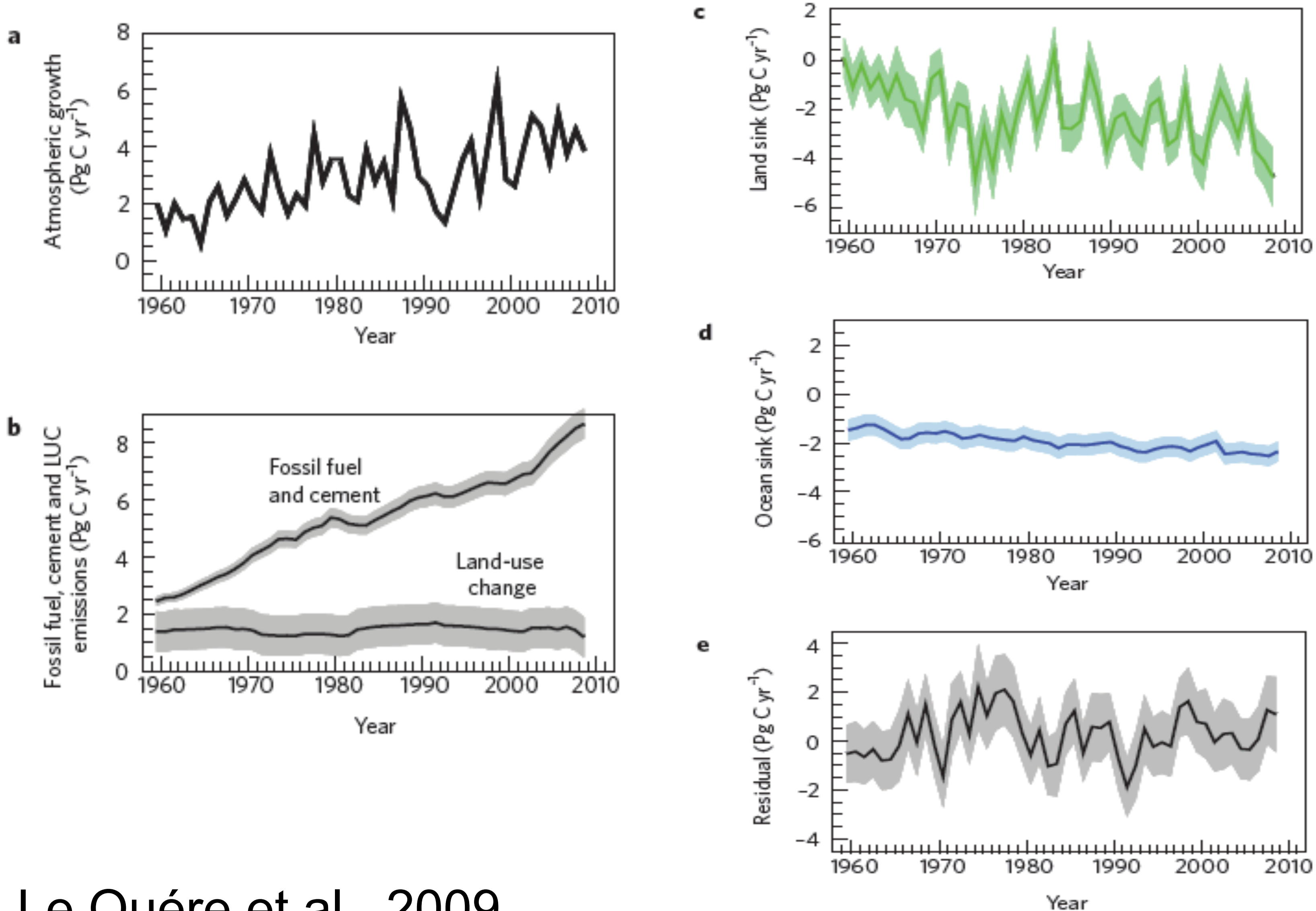
- But: Rate of atmospheric CO_2 increase is about half the rate of emissions increase. **Why?**

Where is the Carbon Going?



Houghton et al. (2007)

Where is the Carbon Going?



Le Quére et al., 2009

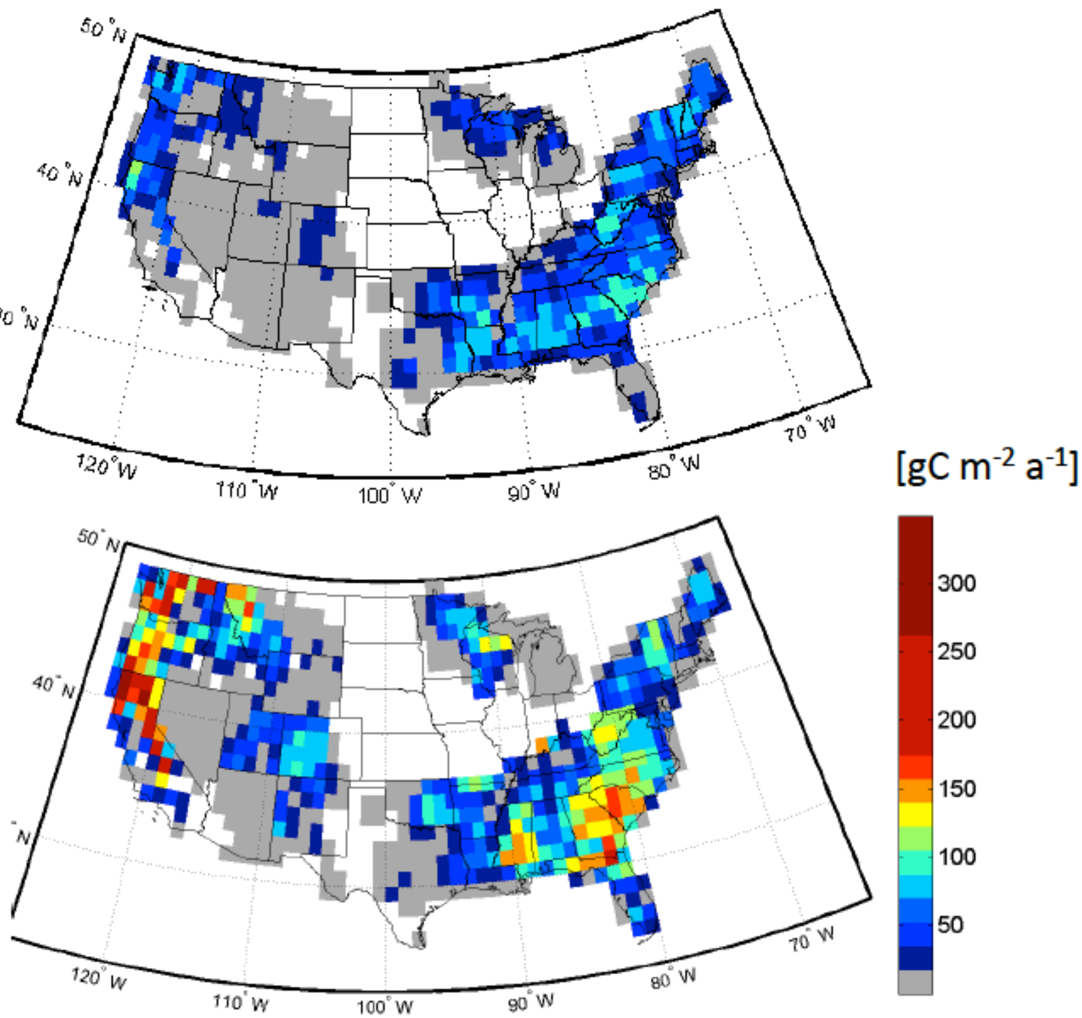
Where is the Carbon Going?

$NEP_{\text{regrowth modeling}}$

160 Tg C a^{-1}

$NEP_{\text{stock change}}$

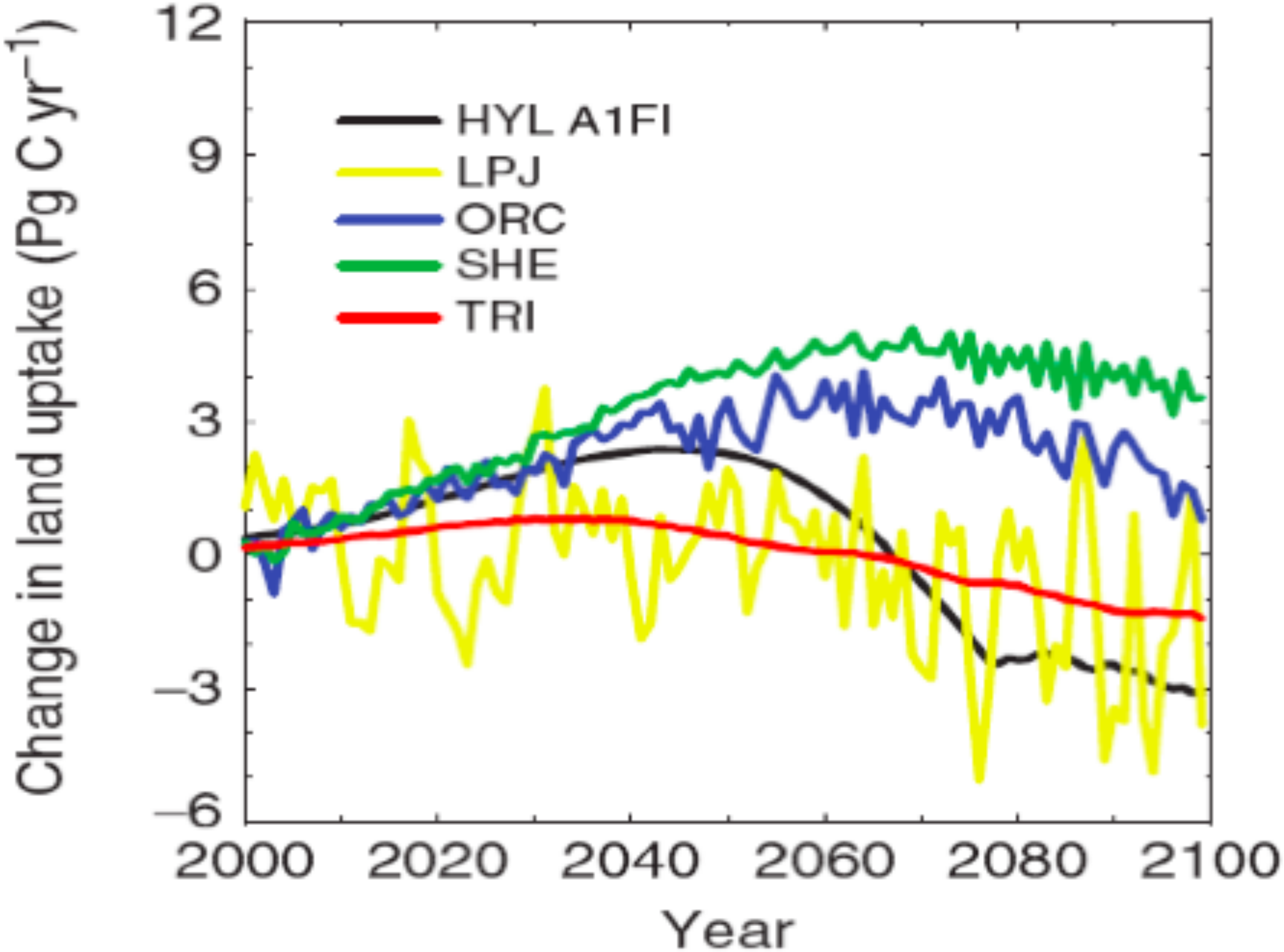
310 Tg C a^{-1}



C. Williams, Clark U, NACP 2011

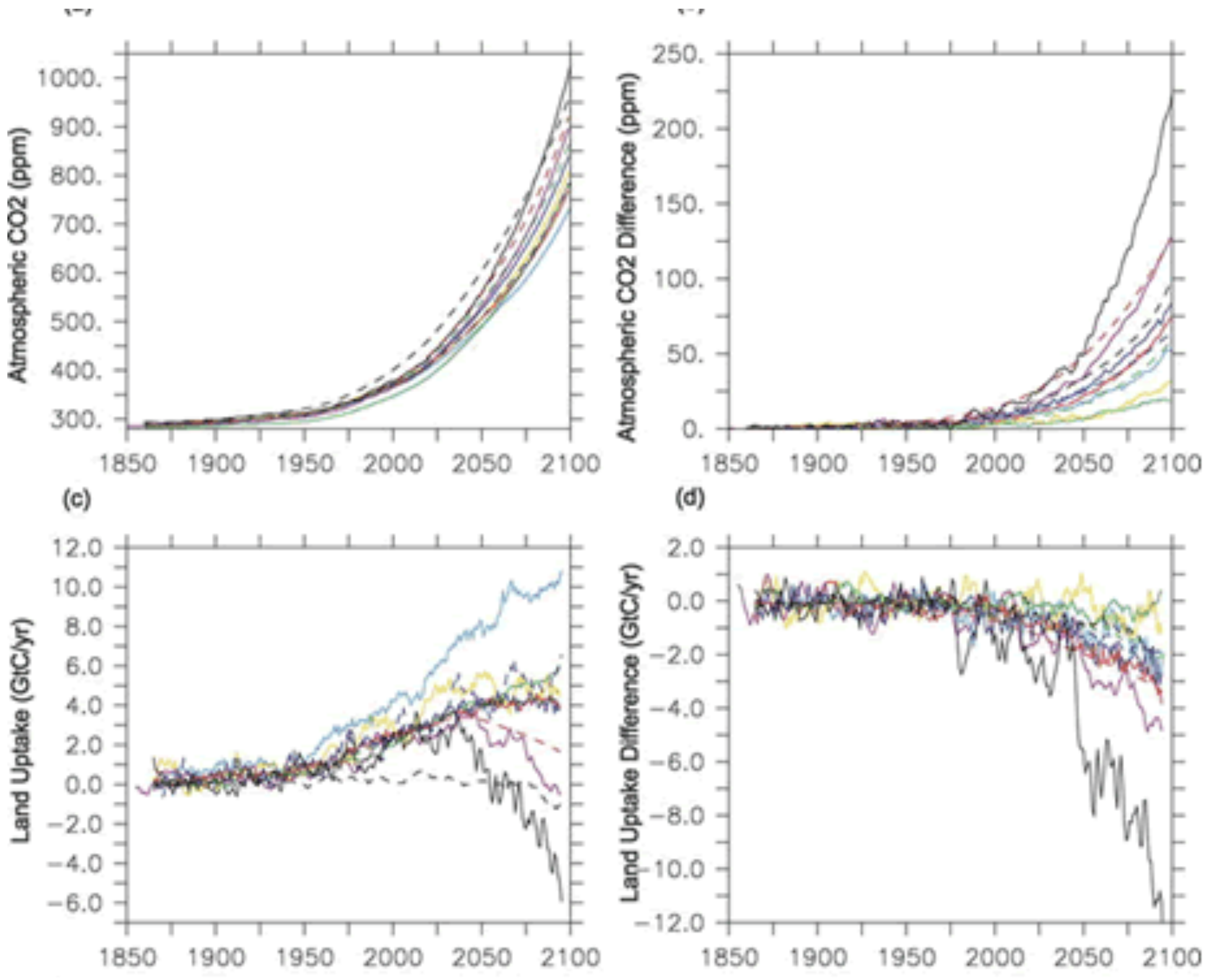
What Don't We Know?

- Sitch et al., 2008



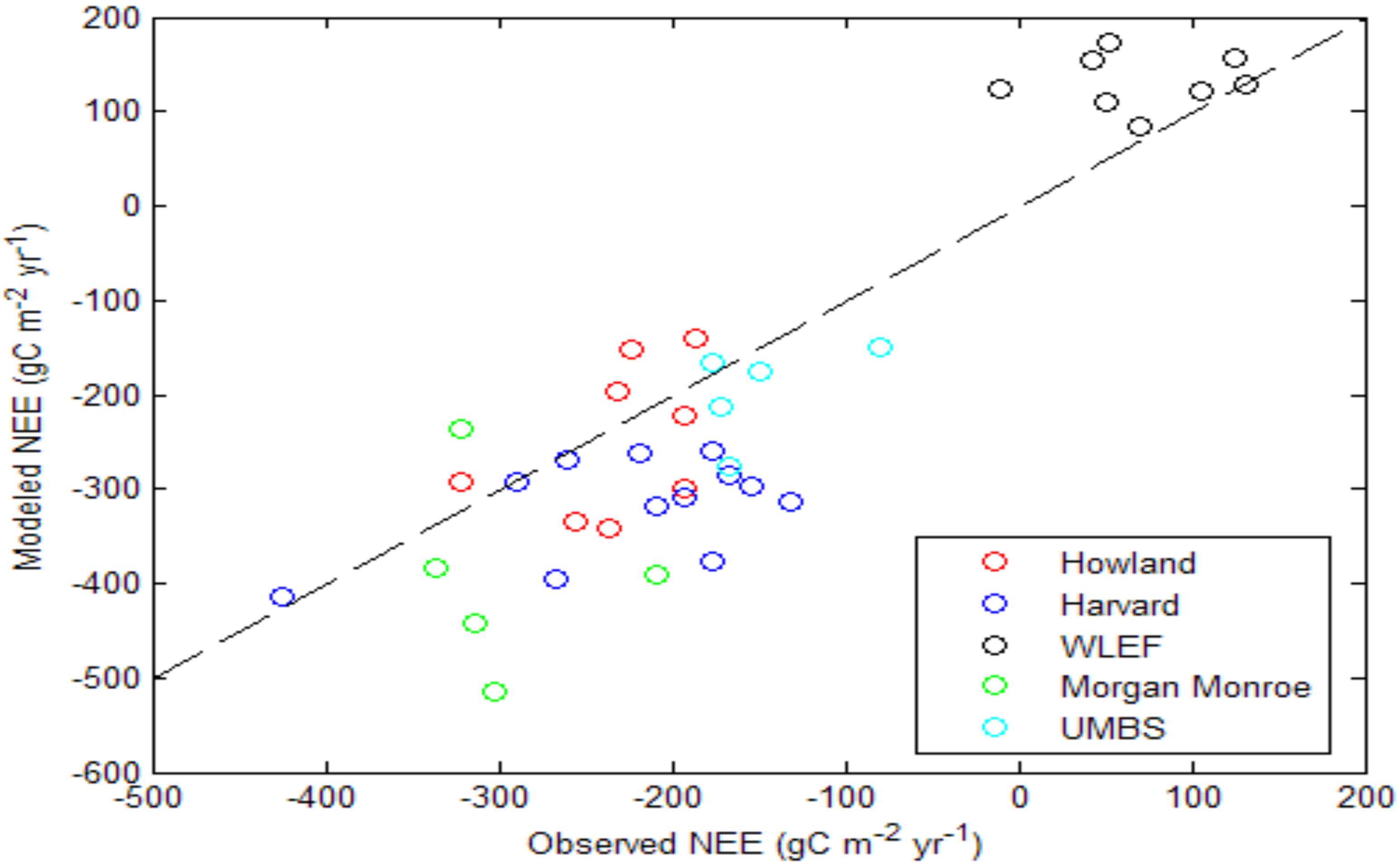
What Don't We Know?

- Friedlingstein et al., 2006



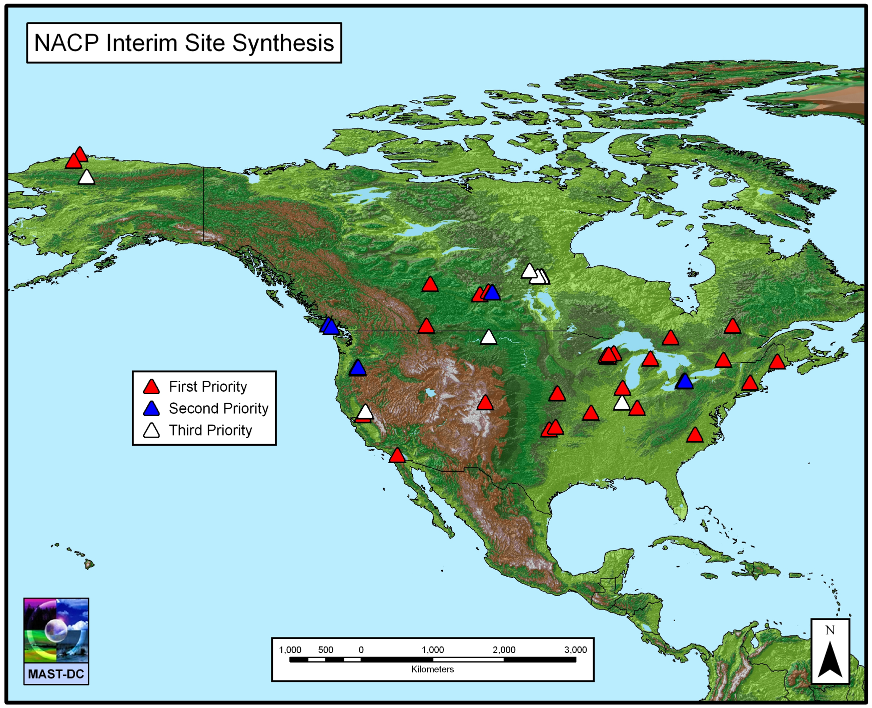
What Don't We Know?

- Ricciuto et al., in prep



Is There Any Consistency to What We Don't Know?

47 Flux Tower Sites



36 AmeriFlux
11 Fluxnet Canada

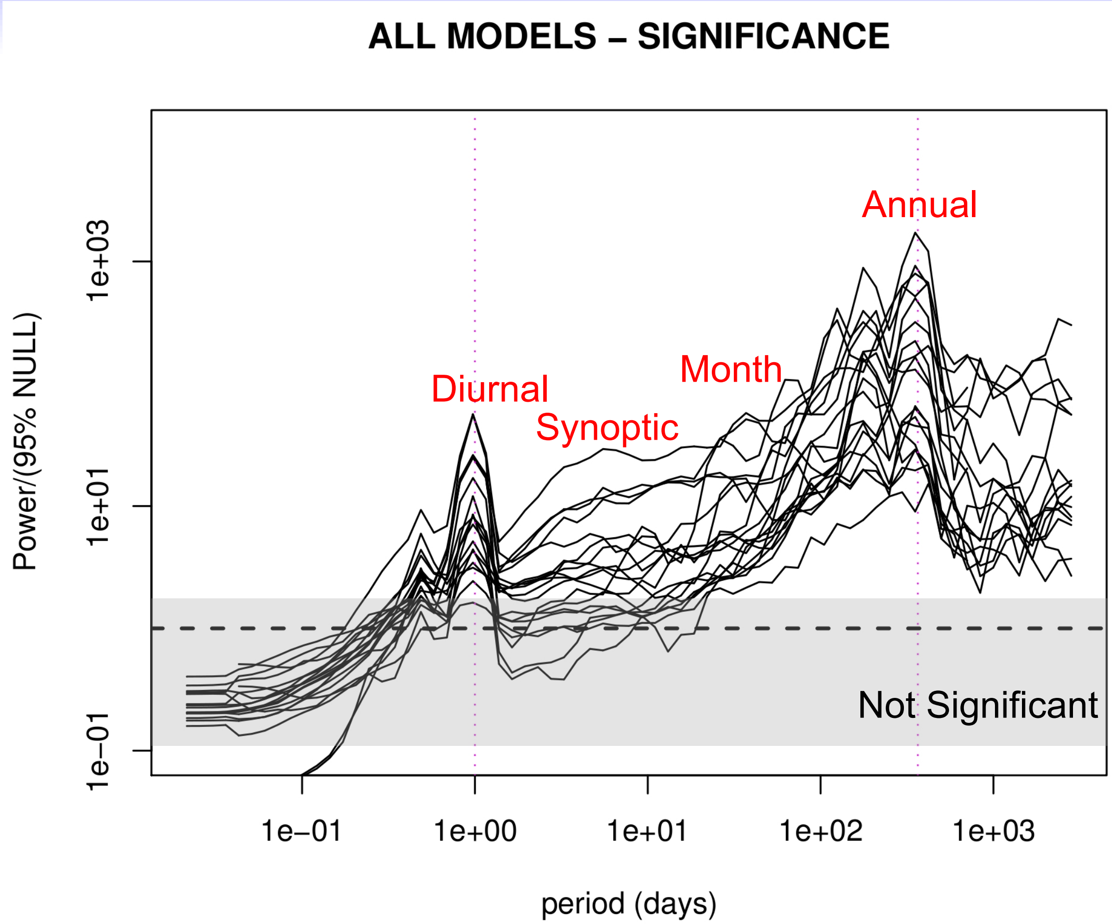
30 Models

Num	Model	Num	Model
1	Agro-IBIS	16	GTEC
2	BEPS	17	ISAM
3	Biome-BGC	18	ISOLSM
4	Can-IBIS	19	LoTEC
5	CLM-CASA'	20	LoTEC-DA
6	CLM-CN	21	LPJ_wsl
7	CN-CLASS	22	ORCHIDEE
8	DAYCENT	23	ORCHIDEE-STICS
9	DLEM	24	SiB3
10	DNDC	25	SiBCASA
11	ecosys	26	SiBCrop
12	ED2	27	SIPNET
13	EDCM	28	SSiB2
14	EPIC	29	TECO
15	GFDL LM3V	30	TRIPLEX-Flux

24 submitted output
10 runs per site

Schwalm et al., 2010

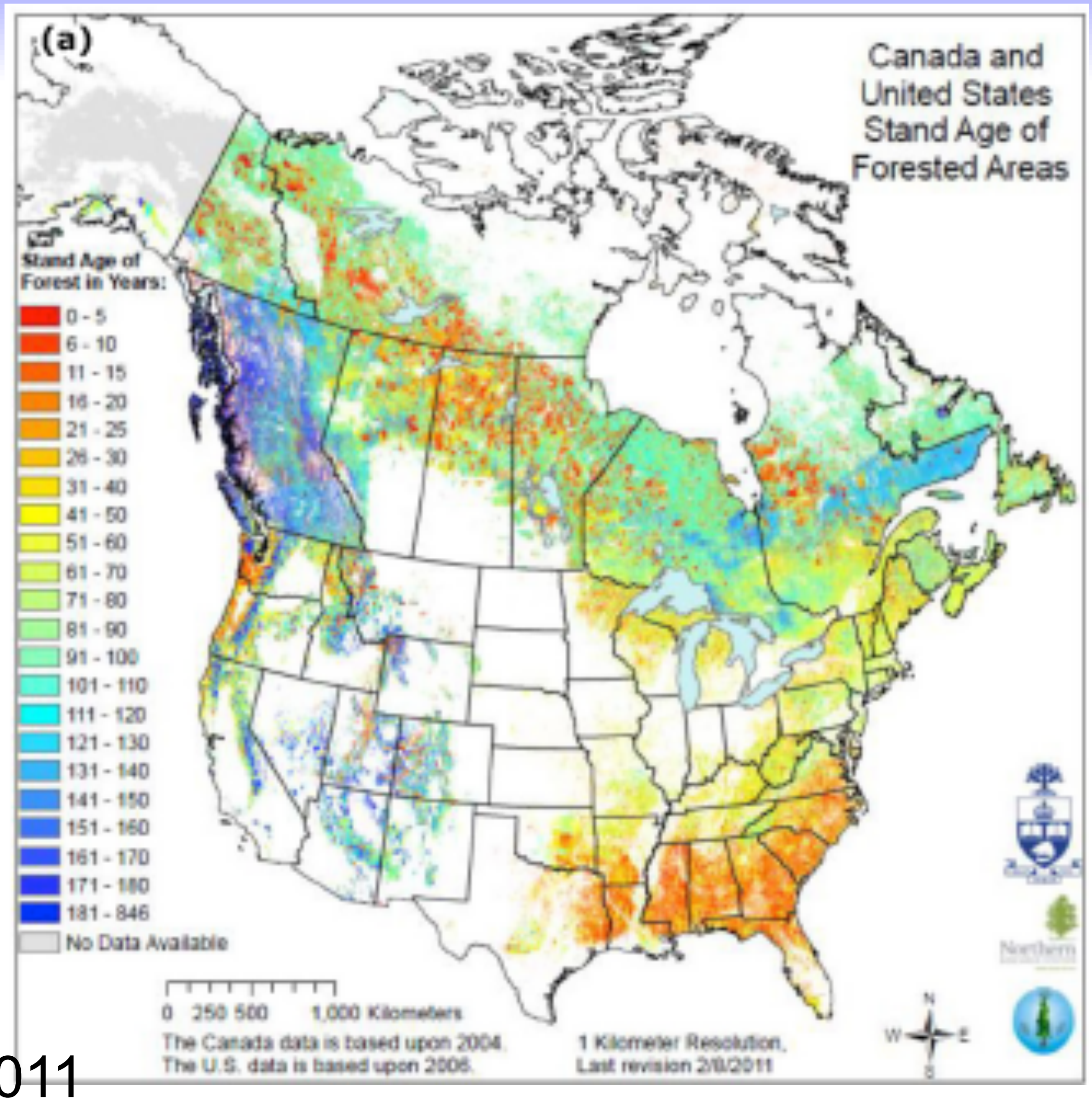
A Little Bit



- Error peak at diurnal & annual time scales
- Errors at synoptic & monthly time scales

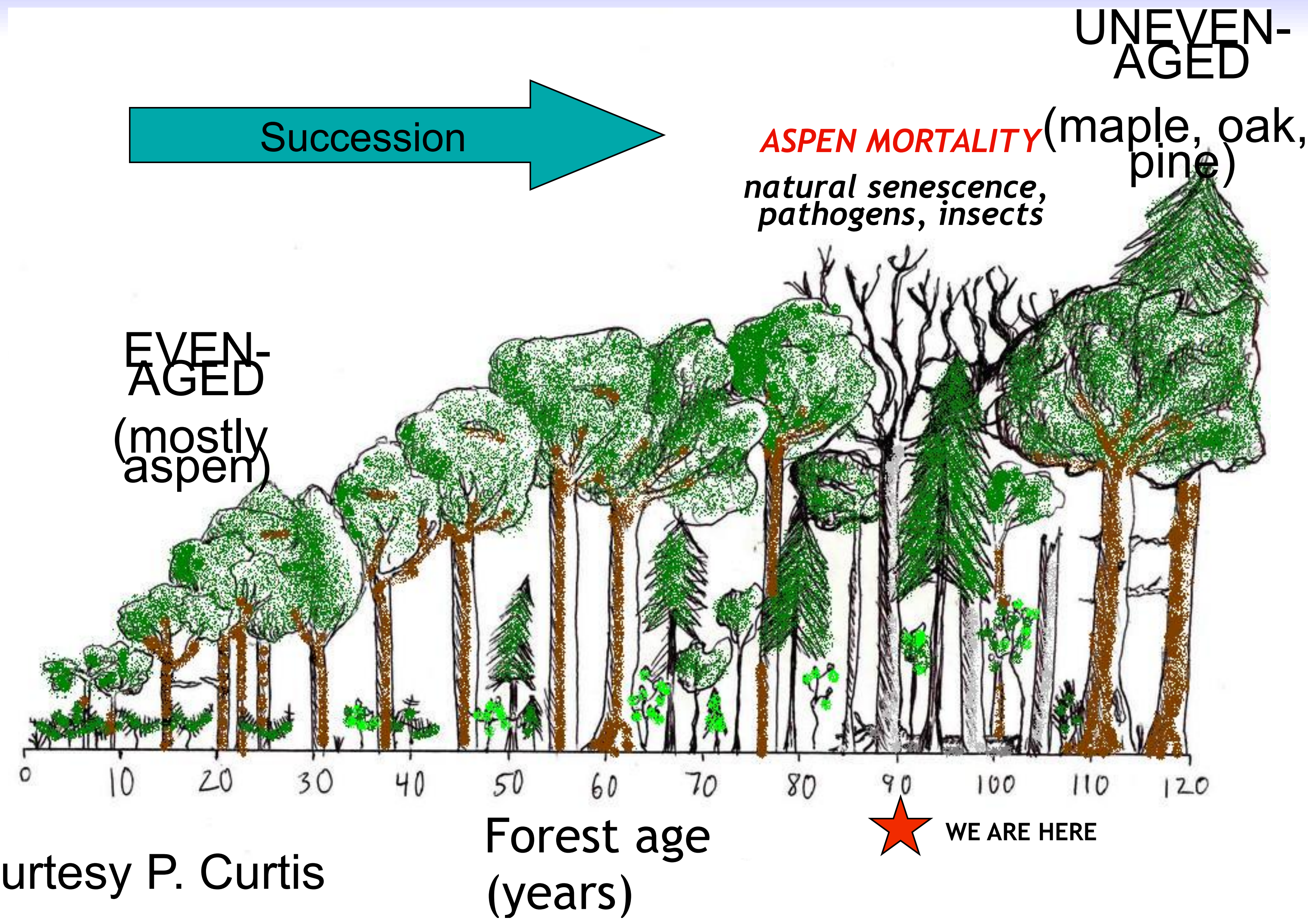
Dietze et al., in review

N America is in Demographic Transition



Pan et al., 2011

N America is in Demographic Transition

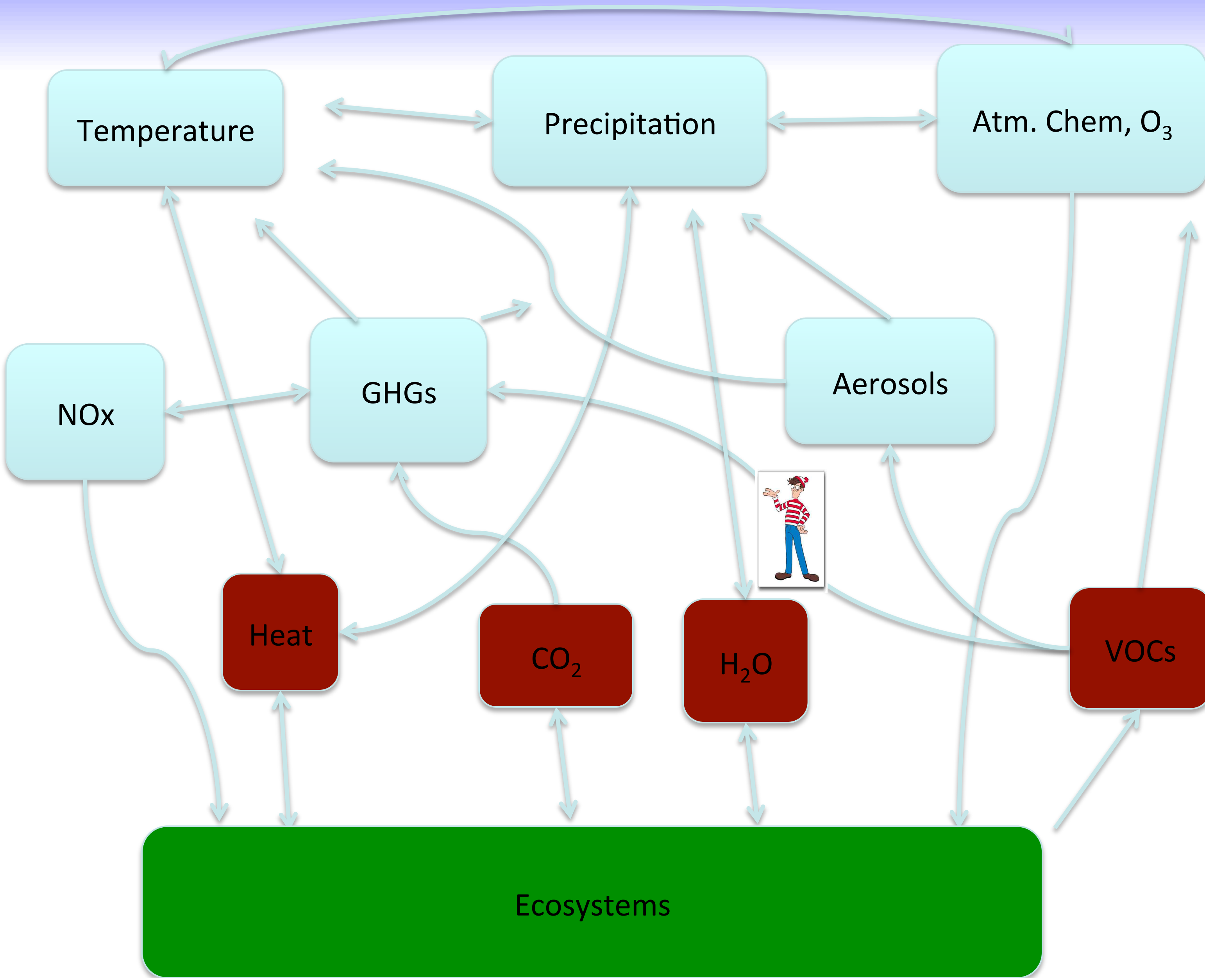


Courtesy P. Curtis

Disturbance Frequency is Poorly Constrained

- Fire: 40,000 km^2/year
- Harvest: 50,000 km^2/year
- Insects: larger
- Storms/hurricanes: > 17,000 km^2/year
- Disease: ???

Find the Surprise!

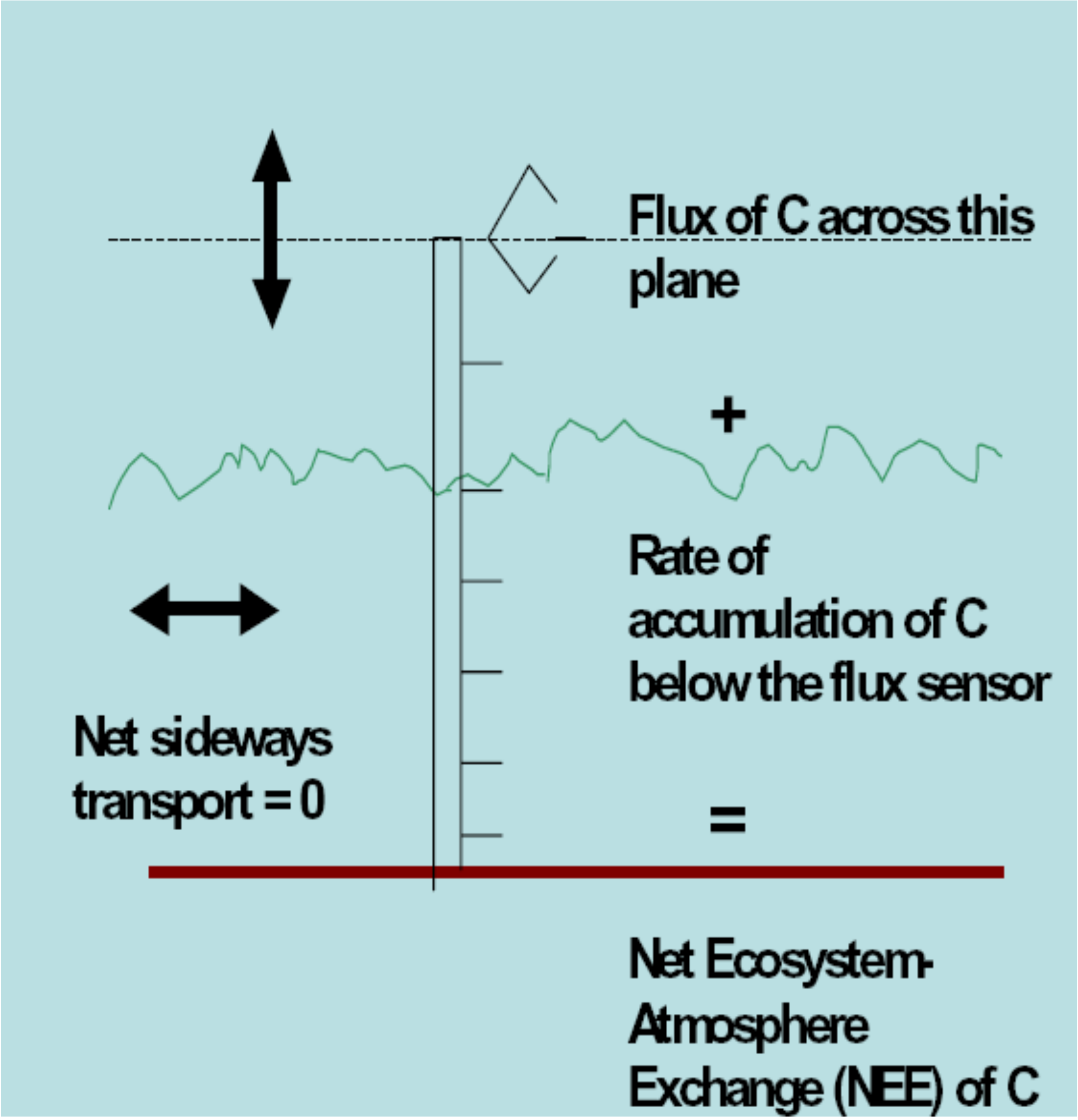


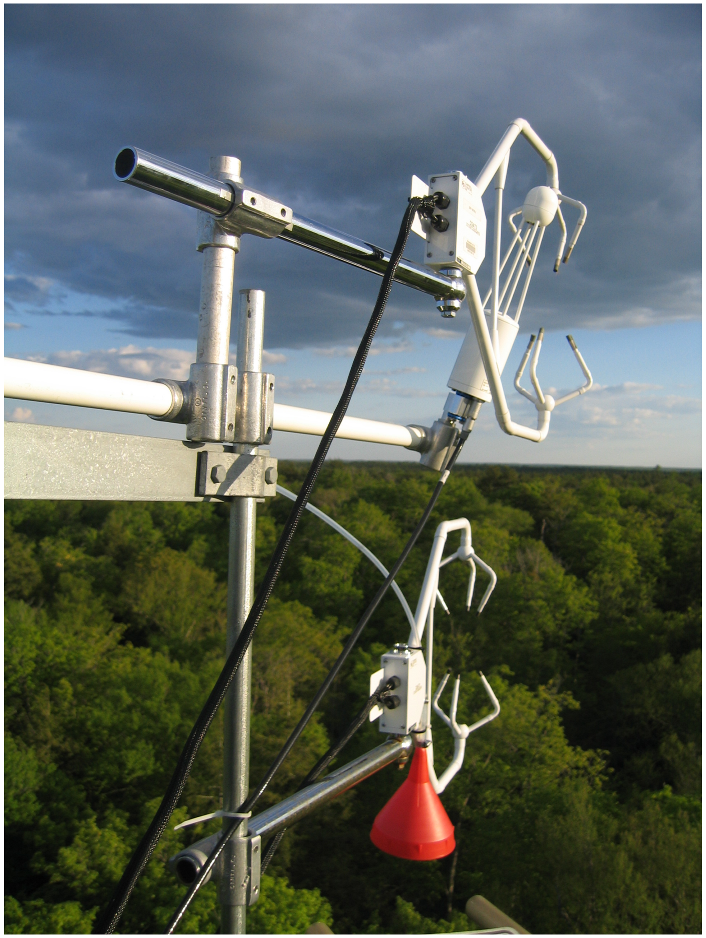
Not This Kind of Surprise

Direct Effects

- Gross Primary Productivity (GPP)
  - PAR, VPD, T, Q_{soil}, $[CO_2]$, N_{avail}
- Ecosystem Respiration (ER)
  - T, Q_{soil}, C:N

Useful Towers

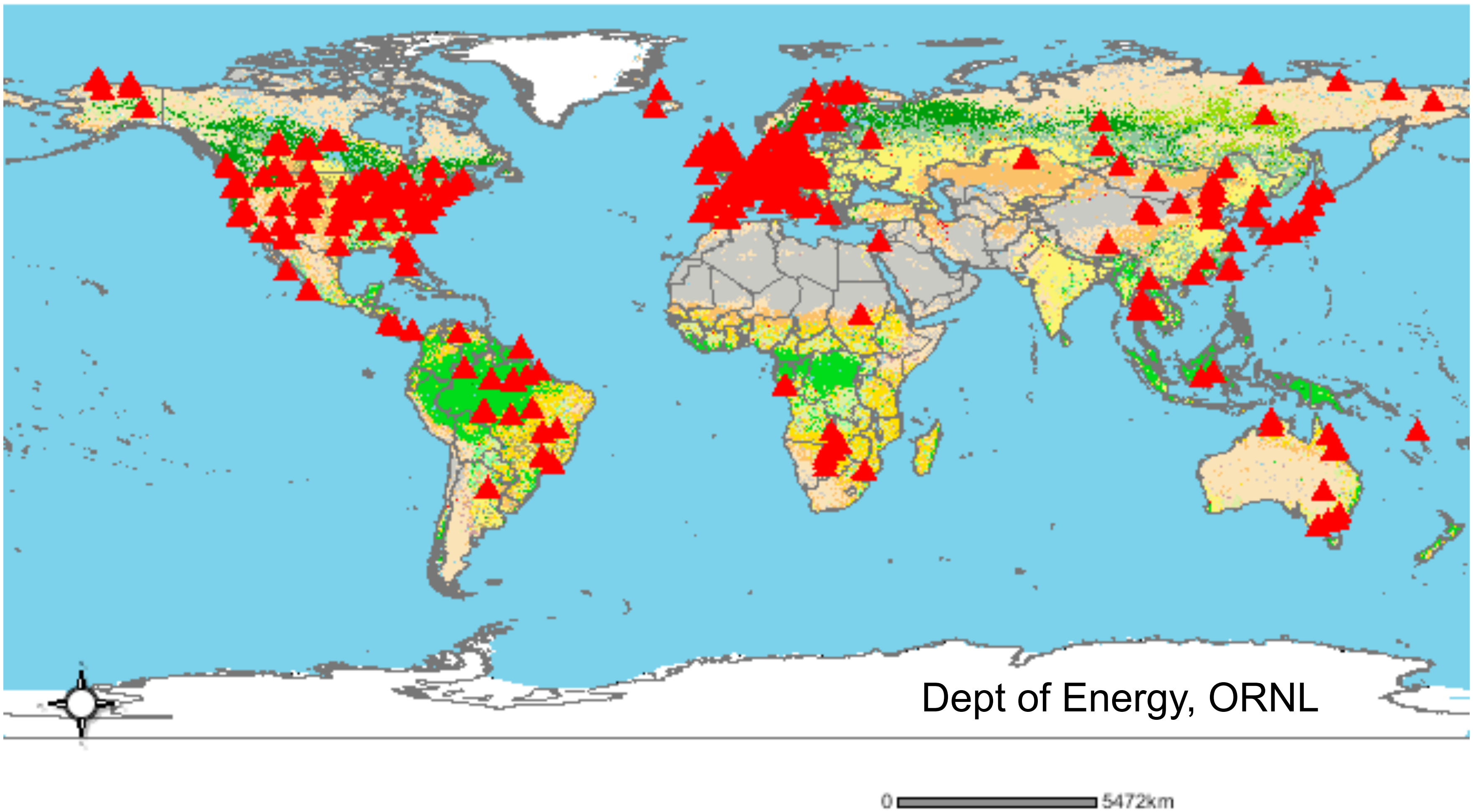




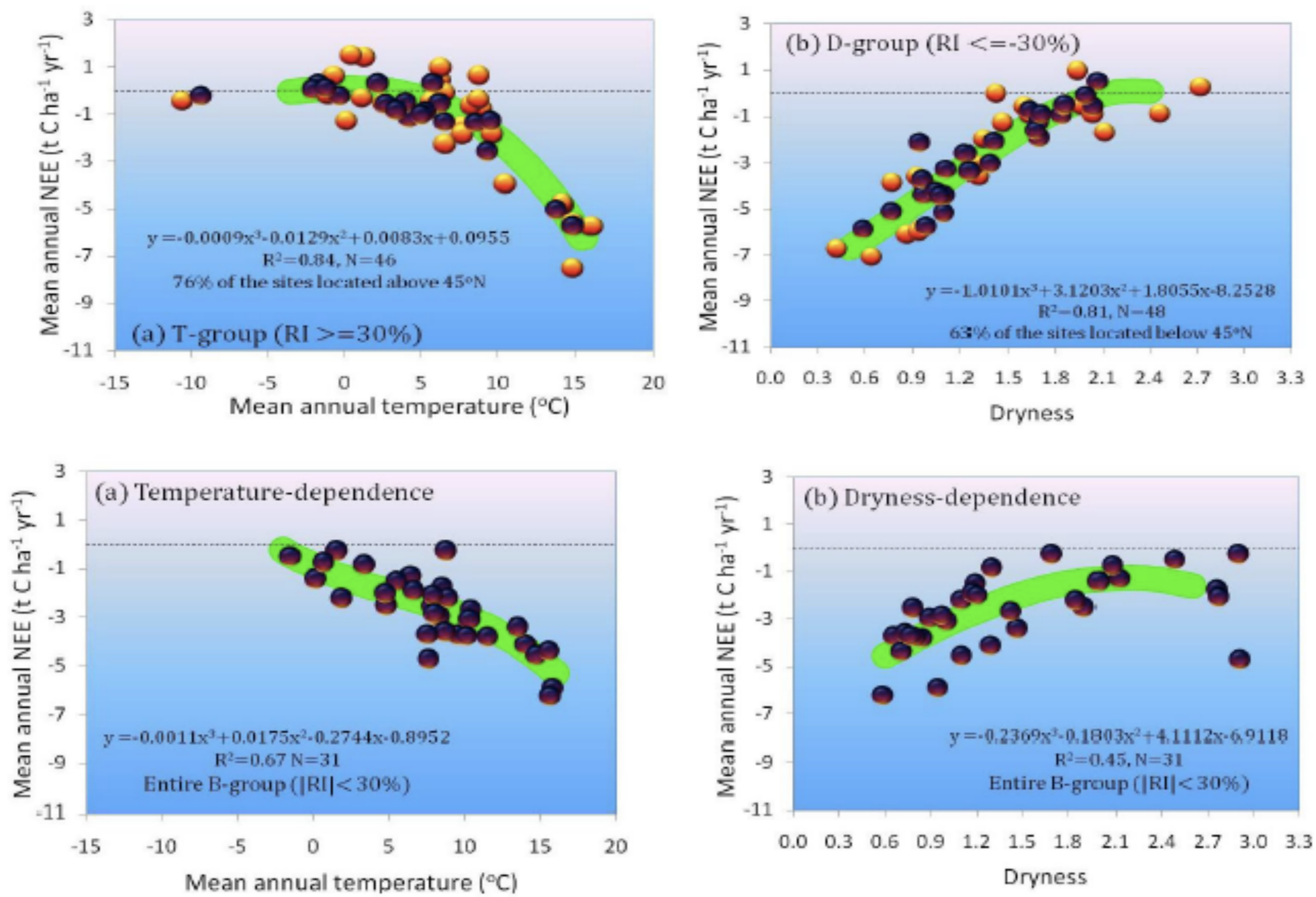
The Value of Network Science

- Ecology is a "synthesis" science

Carpenter et al., 2009

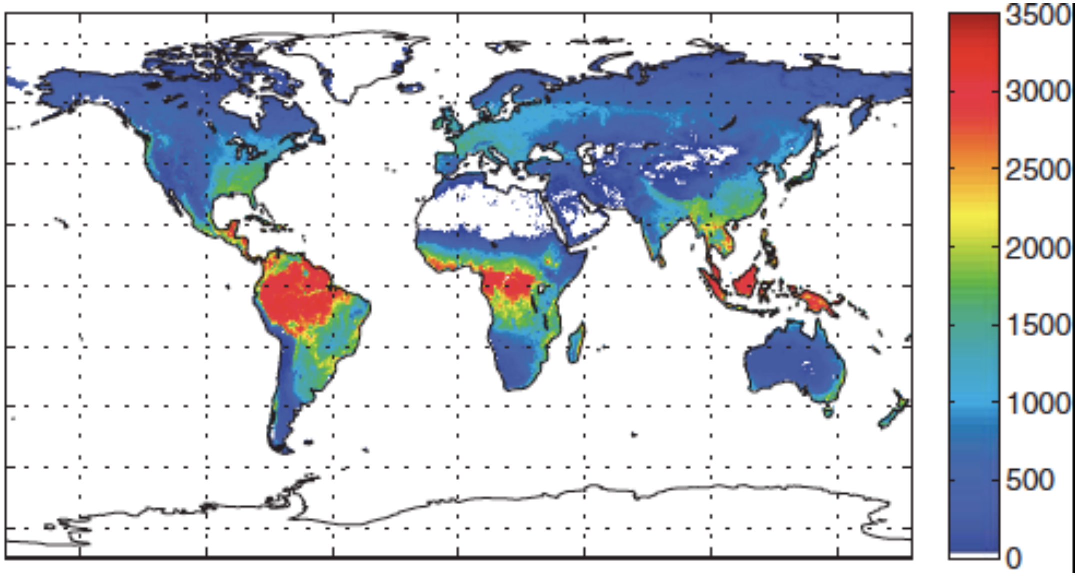


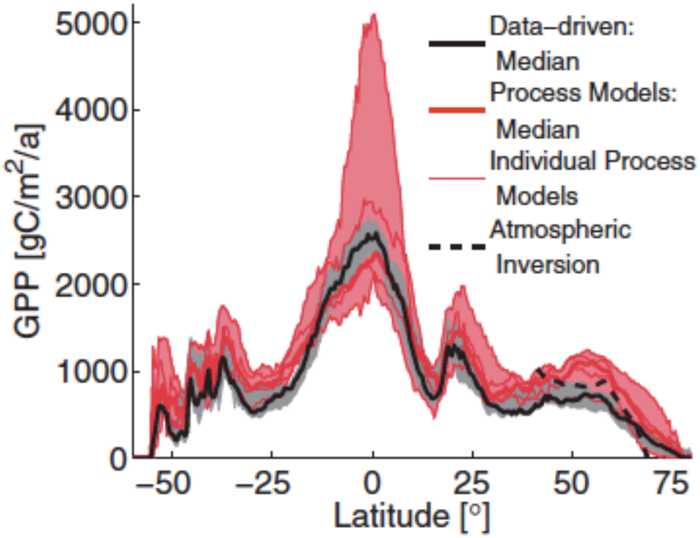
Temperature and Dryness Explain Most NEE Variation Across Space



Yi et al., 2011, ERL

Some Convergence of GPP

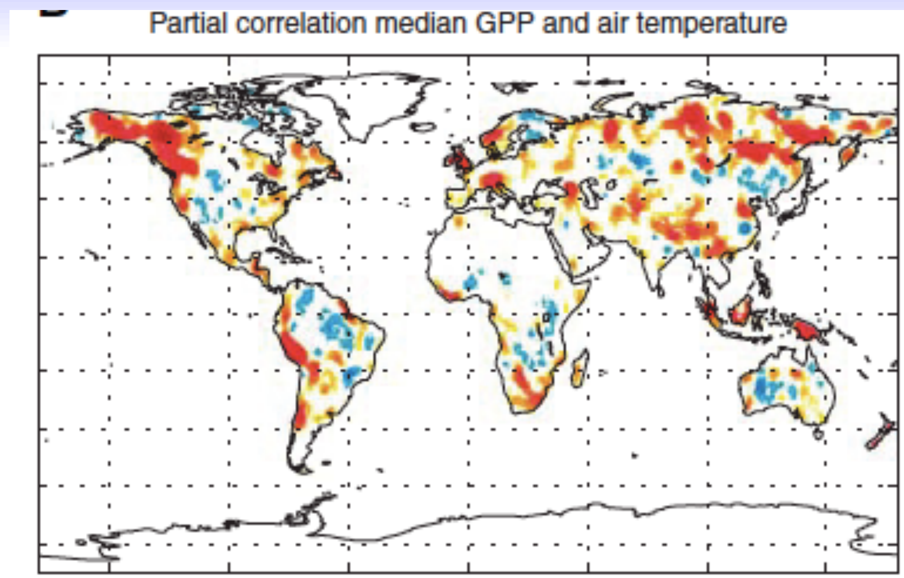


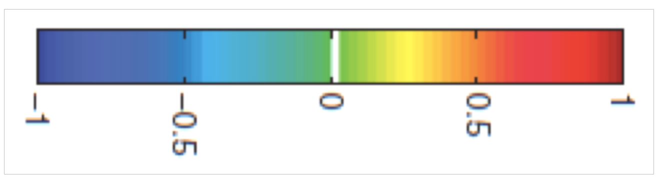


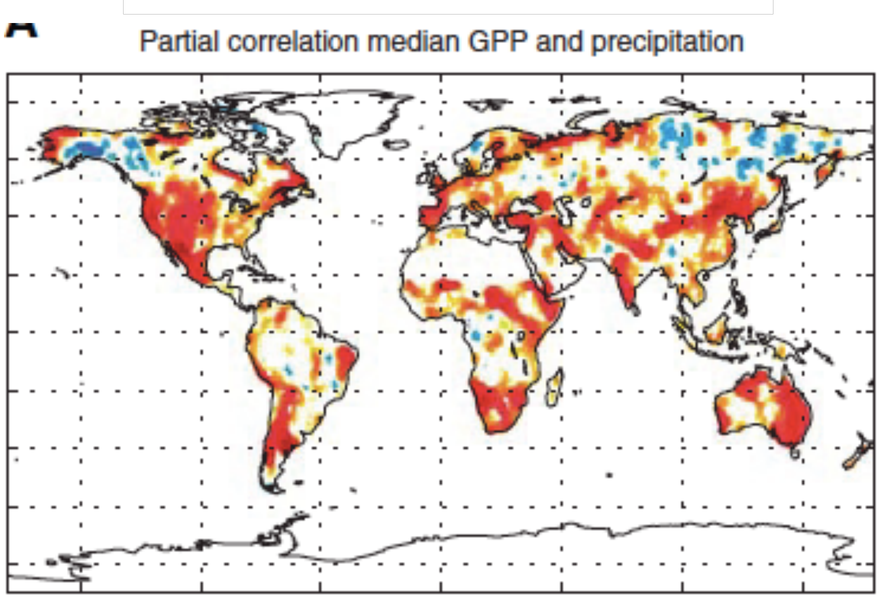
Baer et al., 2010, Science

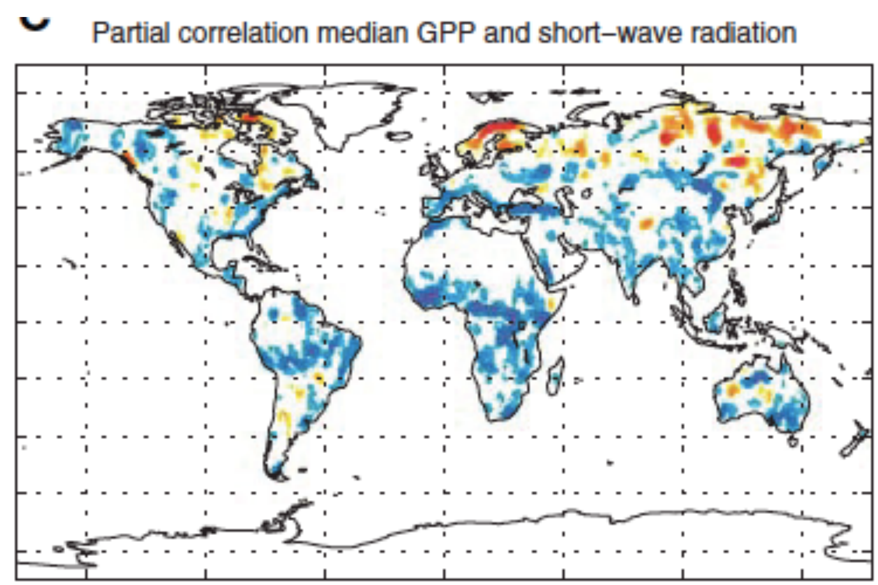
GPP Controls Are Understood?

Baer et al., 2010, Science



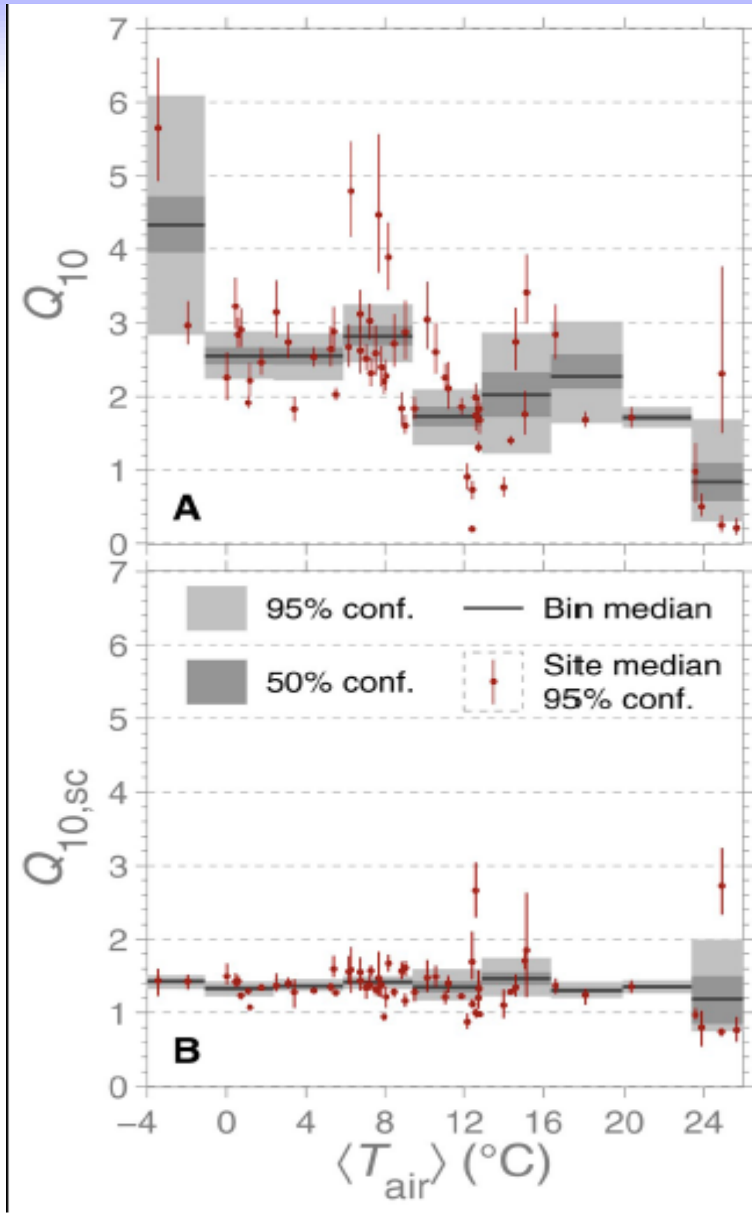






Respiration Sensitivity Converges?

- Low-frequency component of respiration sensitivity to temperature is consistent across space



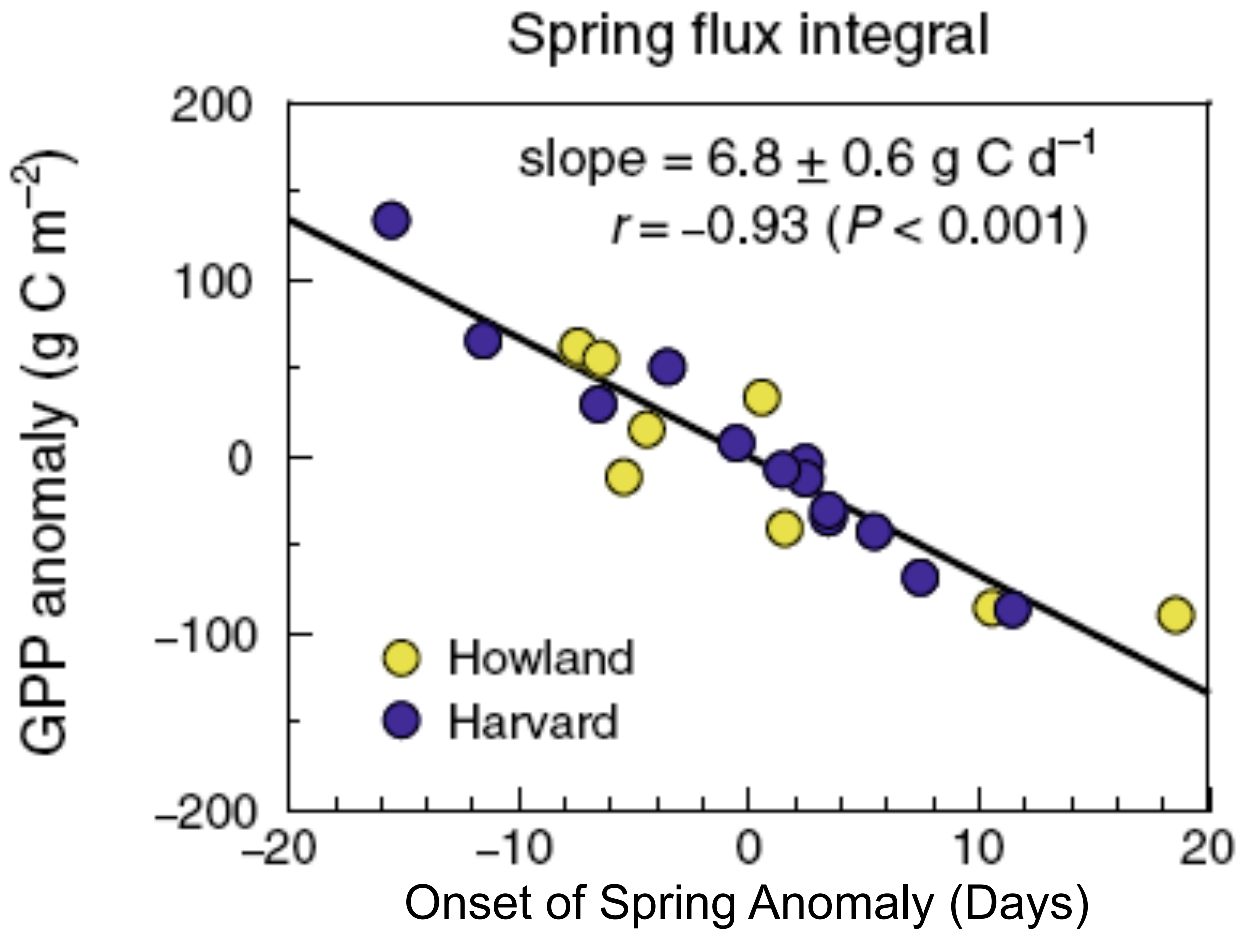
Mahecha et al., 2010, Science

Indirect Effects

- Lagged or coupled responses of climate to carbon uptake
  - Temporal/spatial lags: Phenology, hydrology
  - Forest dynamics (recruitment, mortality, growth): Successional trajectory
  - Disturbance frequency/intensity

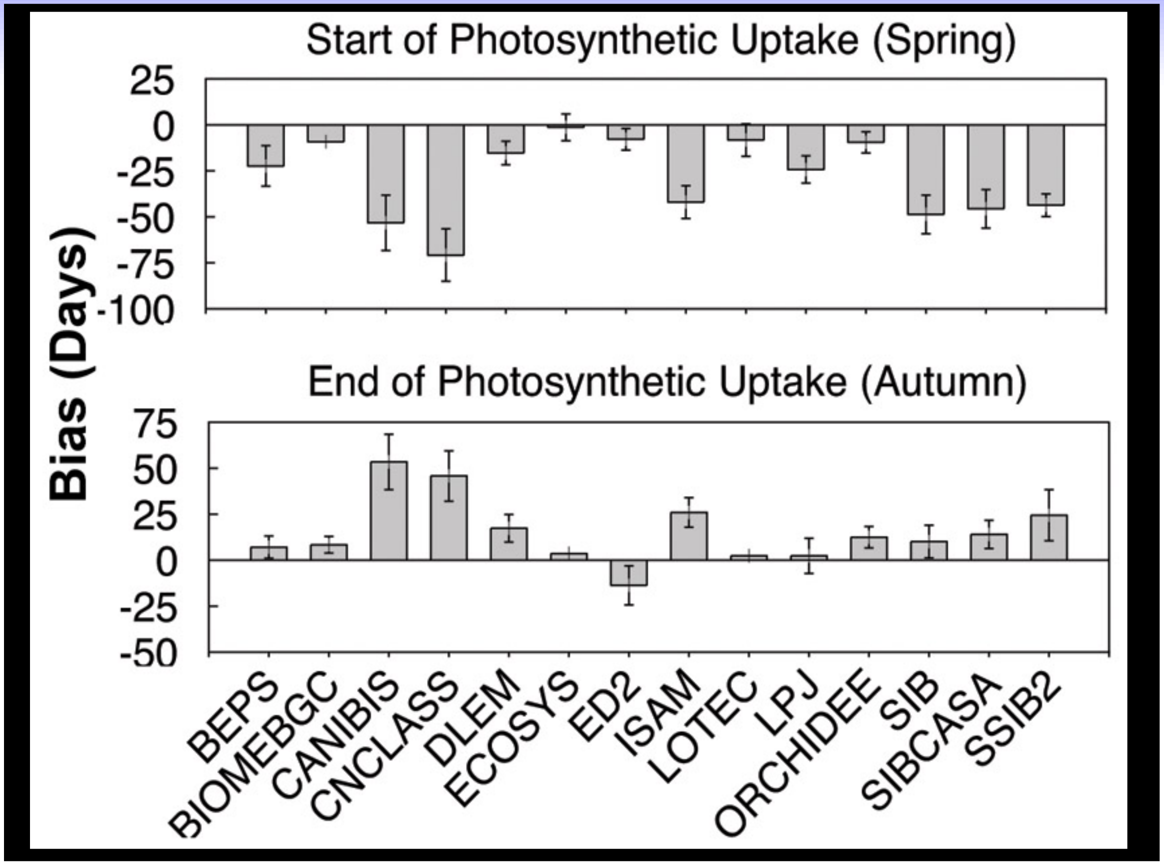
Phenology Explains GPP, too!

Later springs lead to lower productivity in U.S. northeastern forests



Richardson et al. (2009)

Models Overpredict Growing Season Length



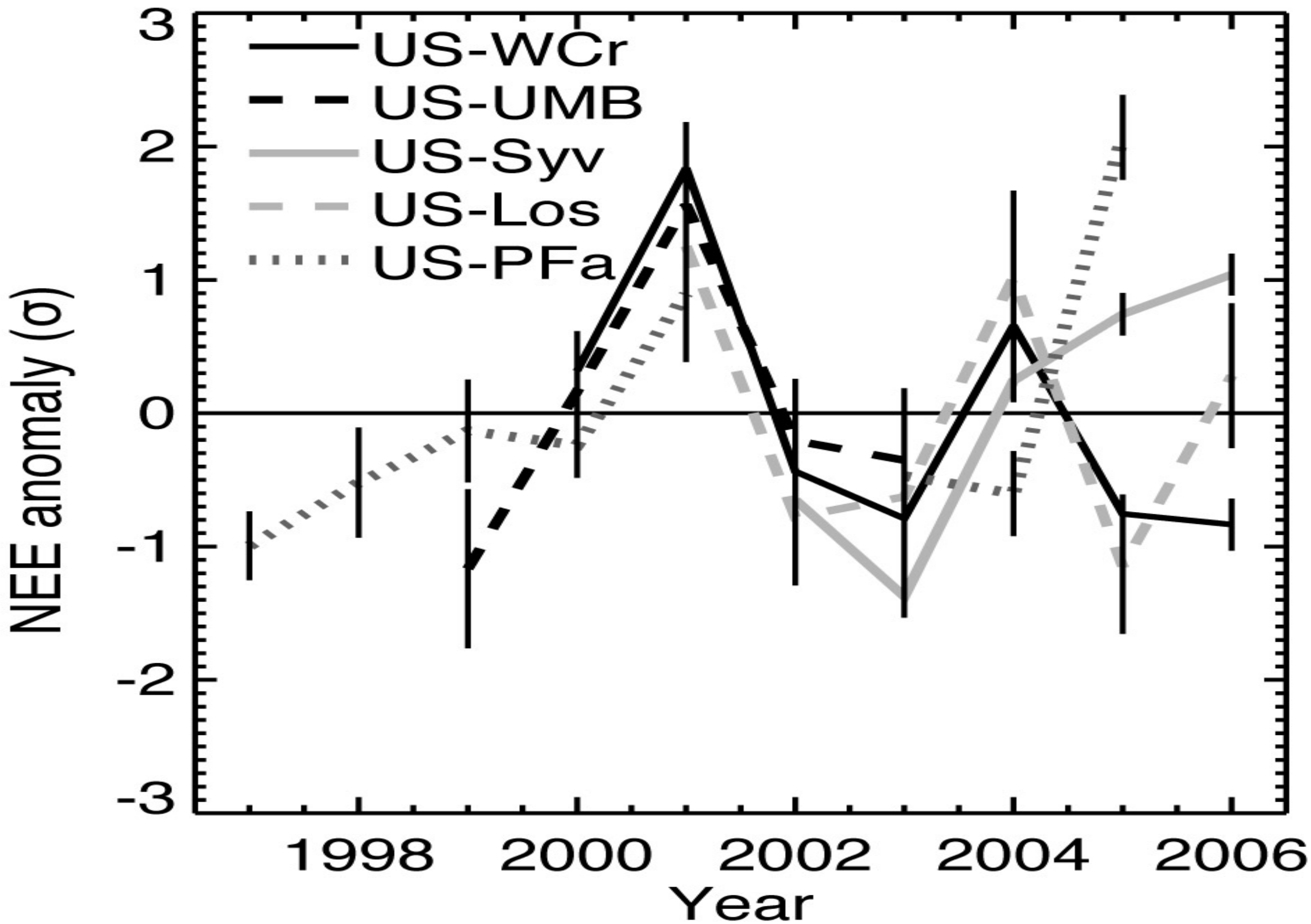
- Early spring/late fall uptake means positive GPP bias

Richardson et al., submitted

What About at the Regional Scale?

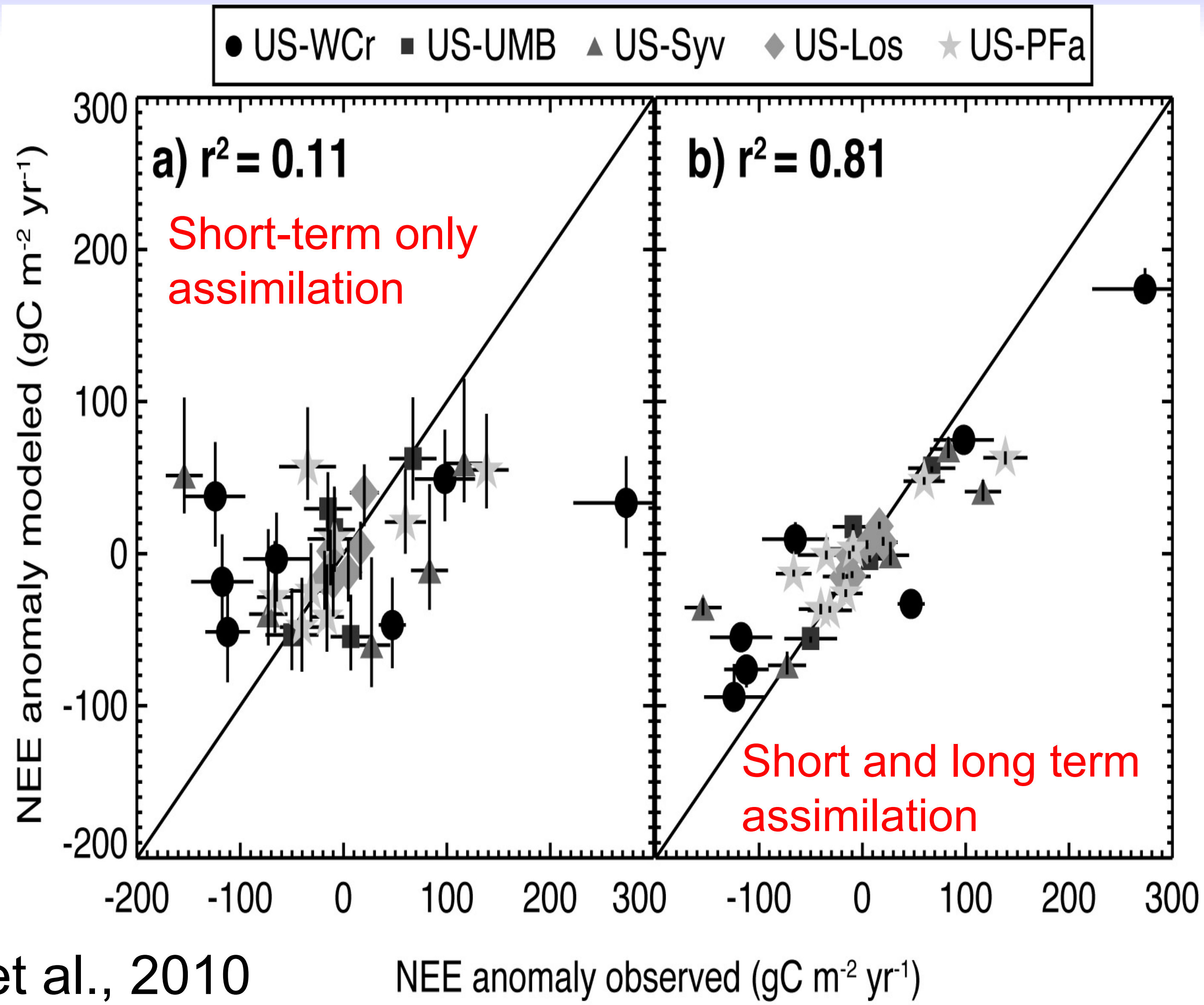
- Chequamegon Ecosystem-Atmosphere Study (ChEAS)

Coherent Carbon Sinks Imply Climatic Forcing of Interannual Variability



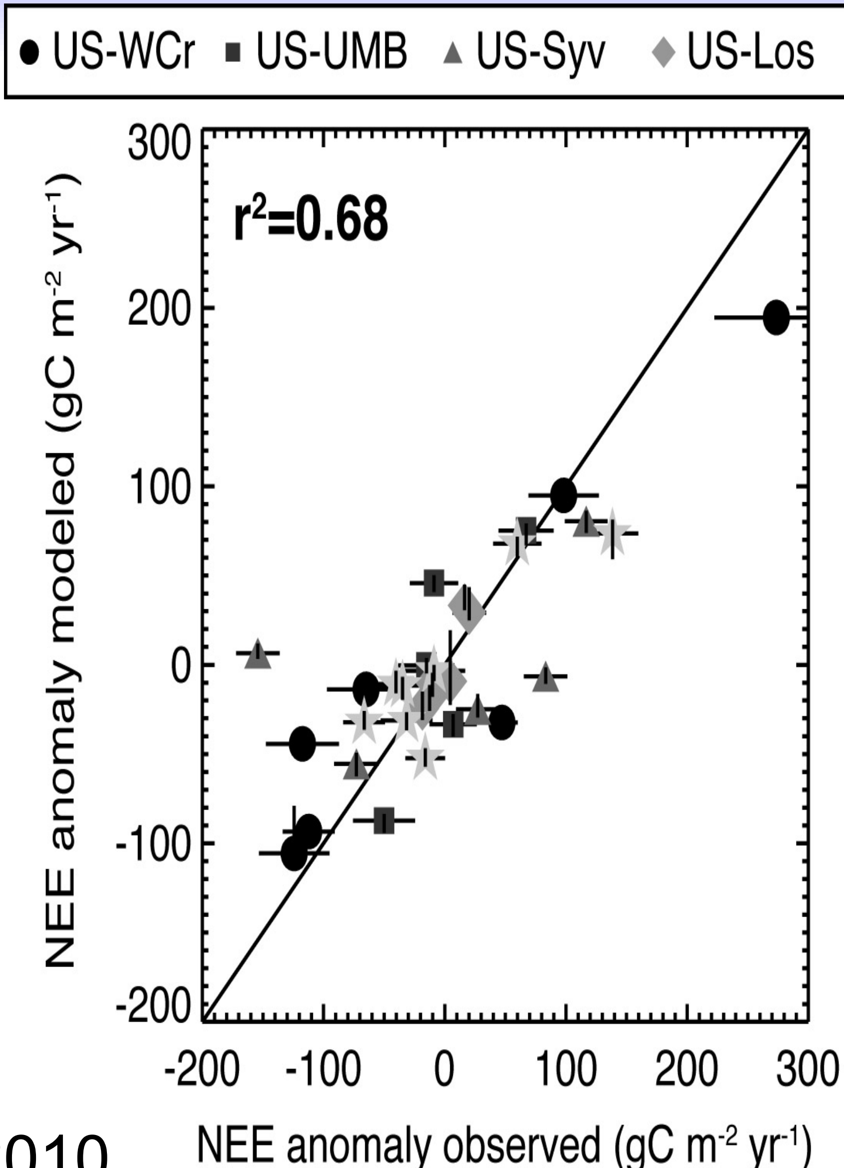
Desai et al., 2010

Model-Data Assimilation Shows Predictive Skill with Phenology



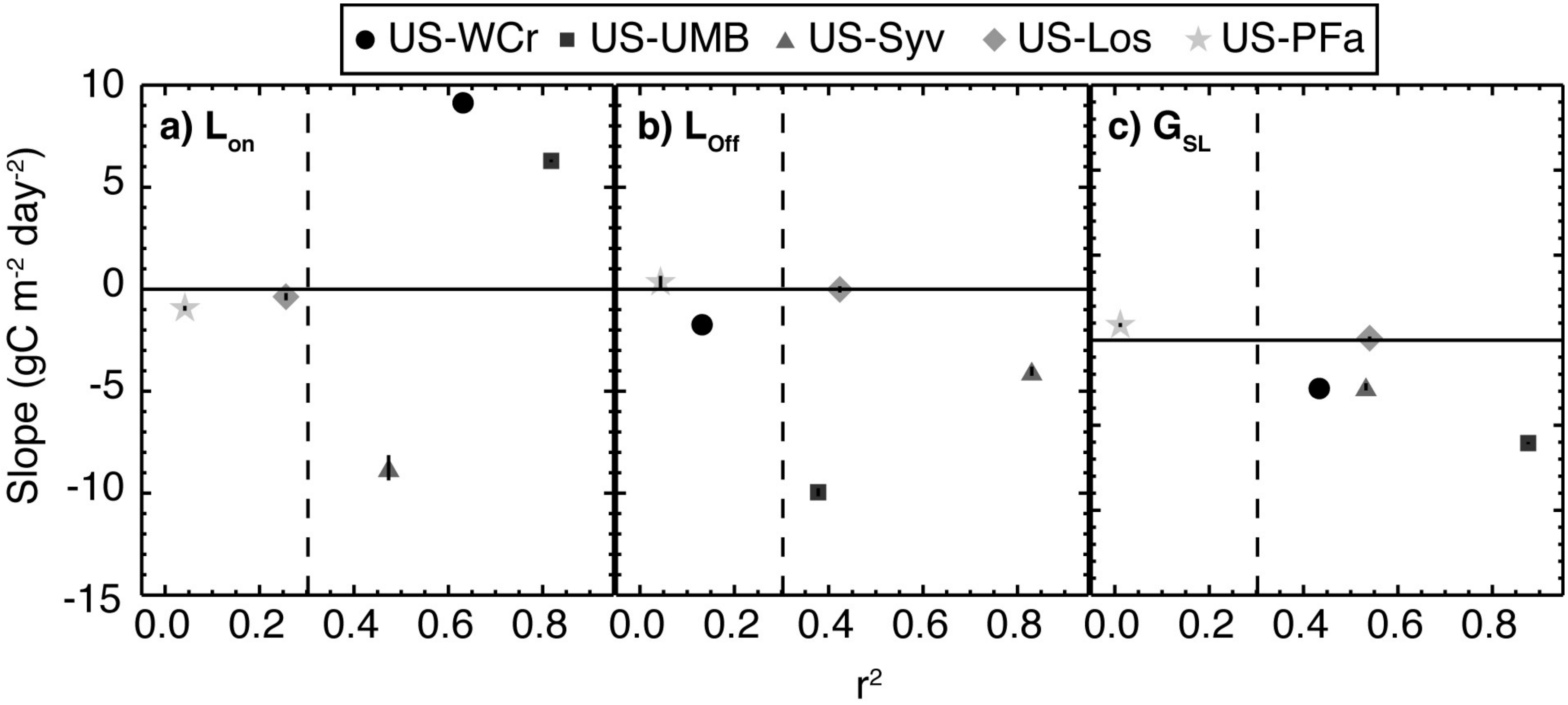
Desai et al., 2010

Even When Model is Forced to Maintain Coherent Phenology



Desai et al., 2010

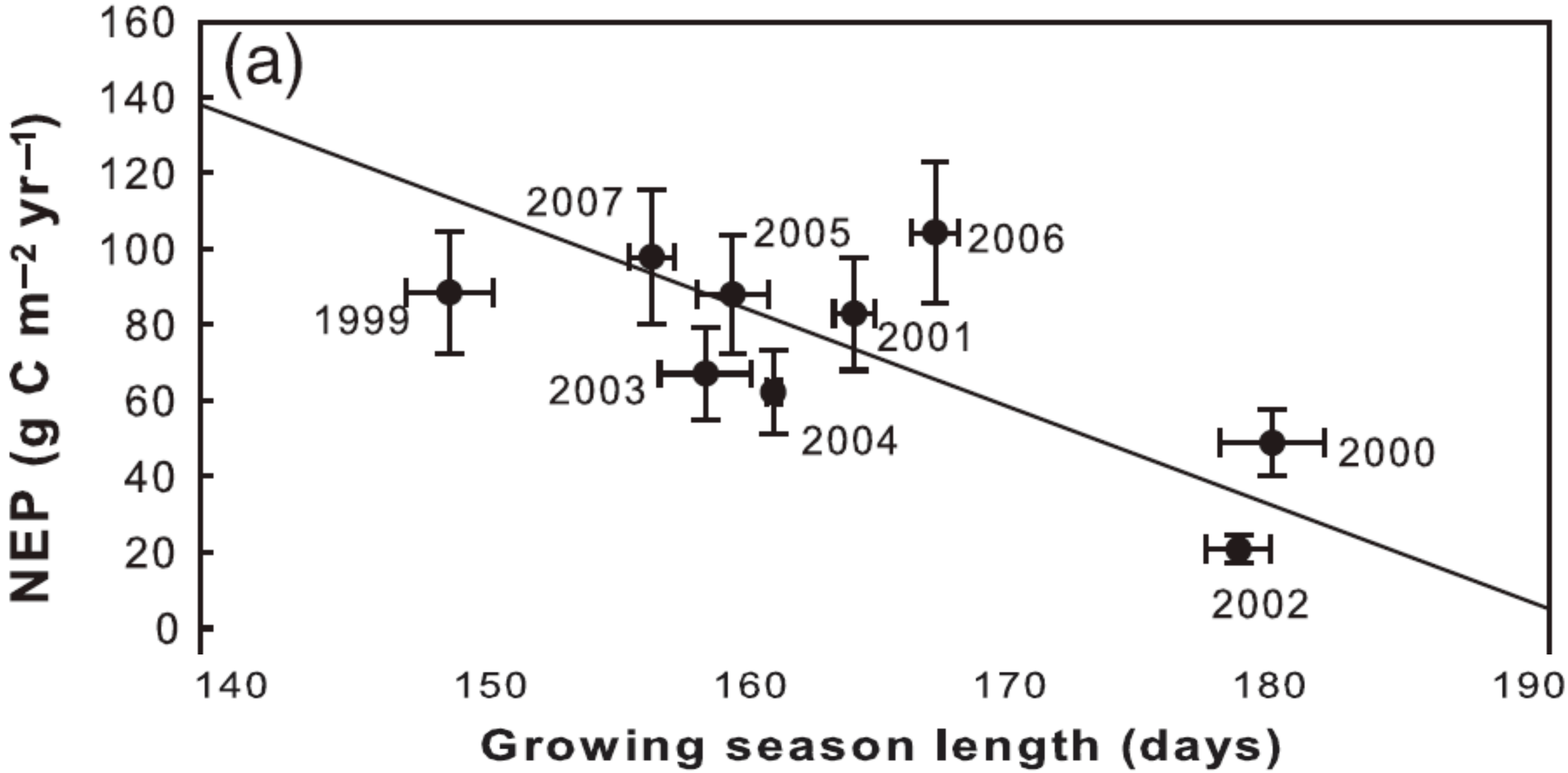
But Model Explains Coherent Flux Differently Depending on Ecosystem



Desai et al., 2010

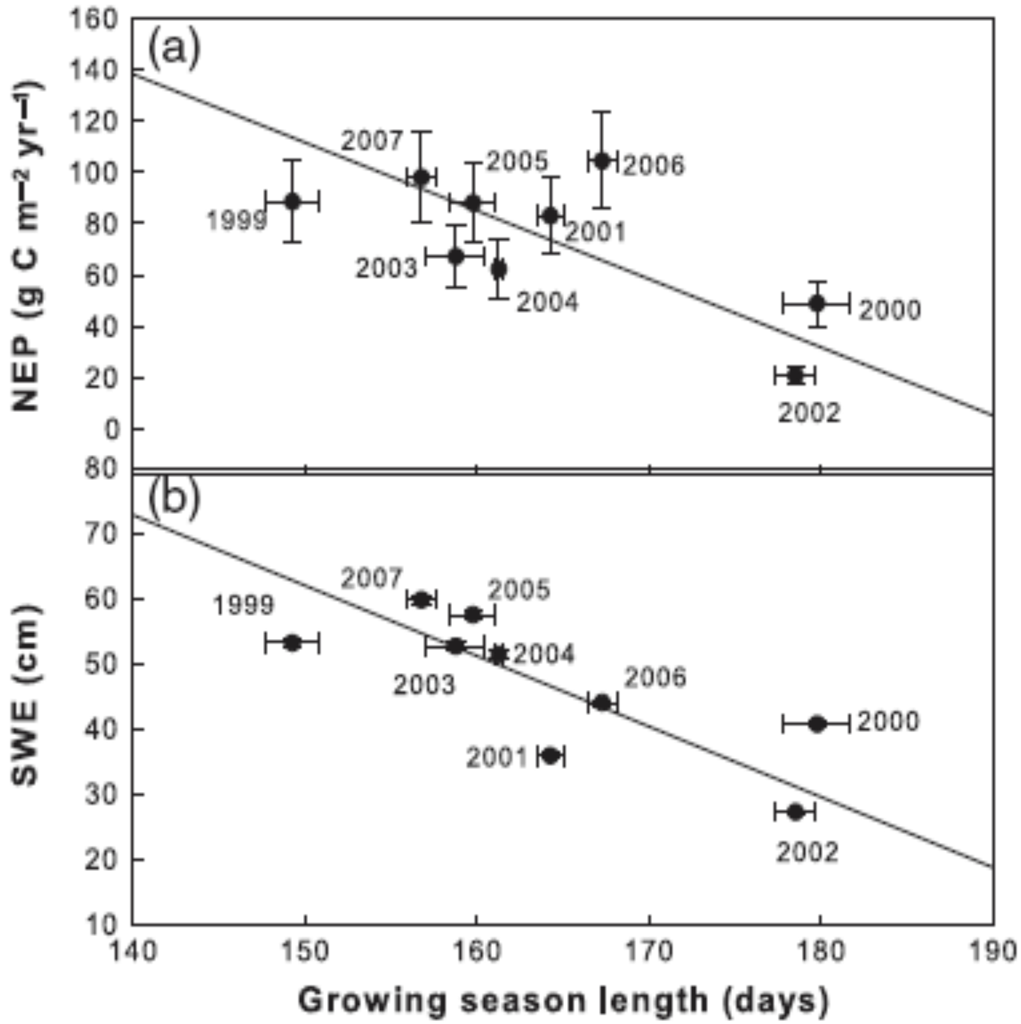
Phenology is Not Simple!

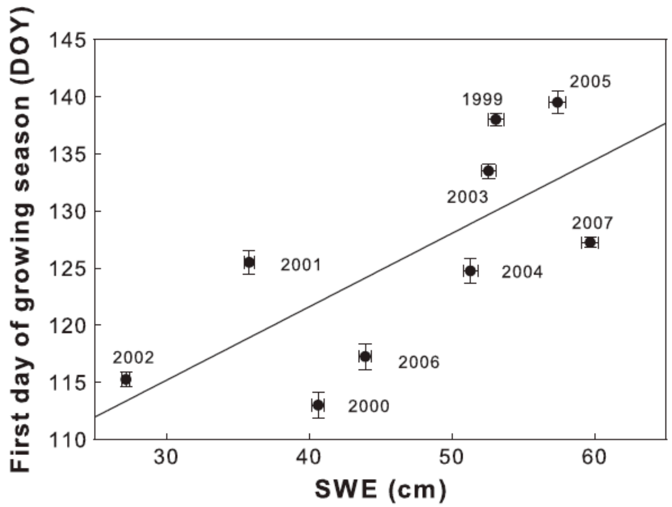
- Niwot Ridge Ameriflux subalpine fir/spruce
  - 3050m elevation



Hu et al. (2010), Sacks et al. (2006)

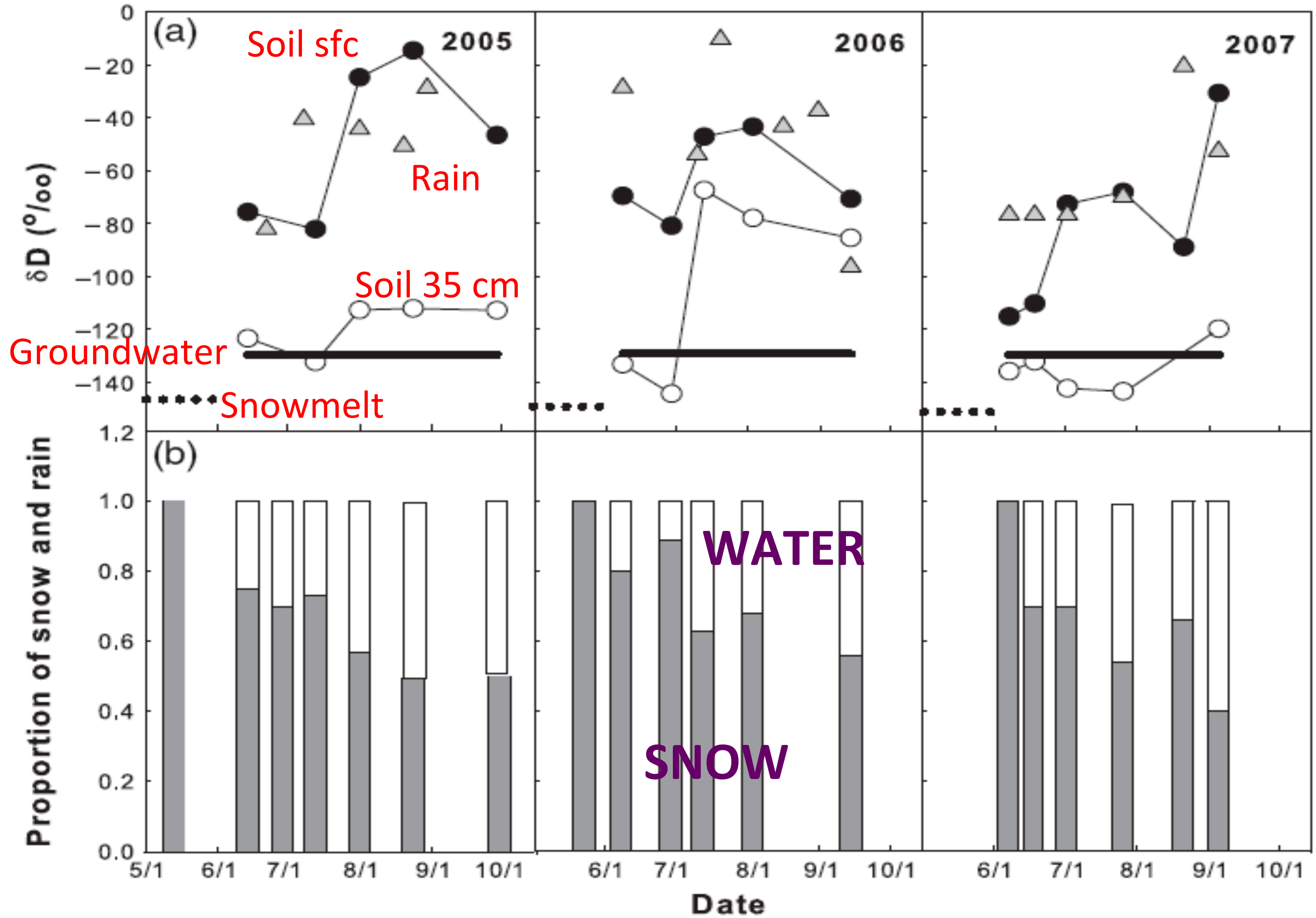
Moisture Matters





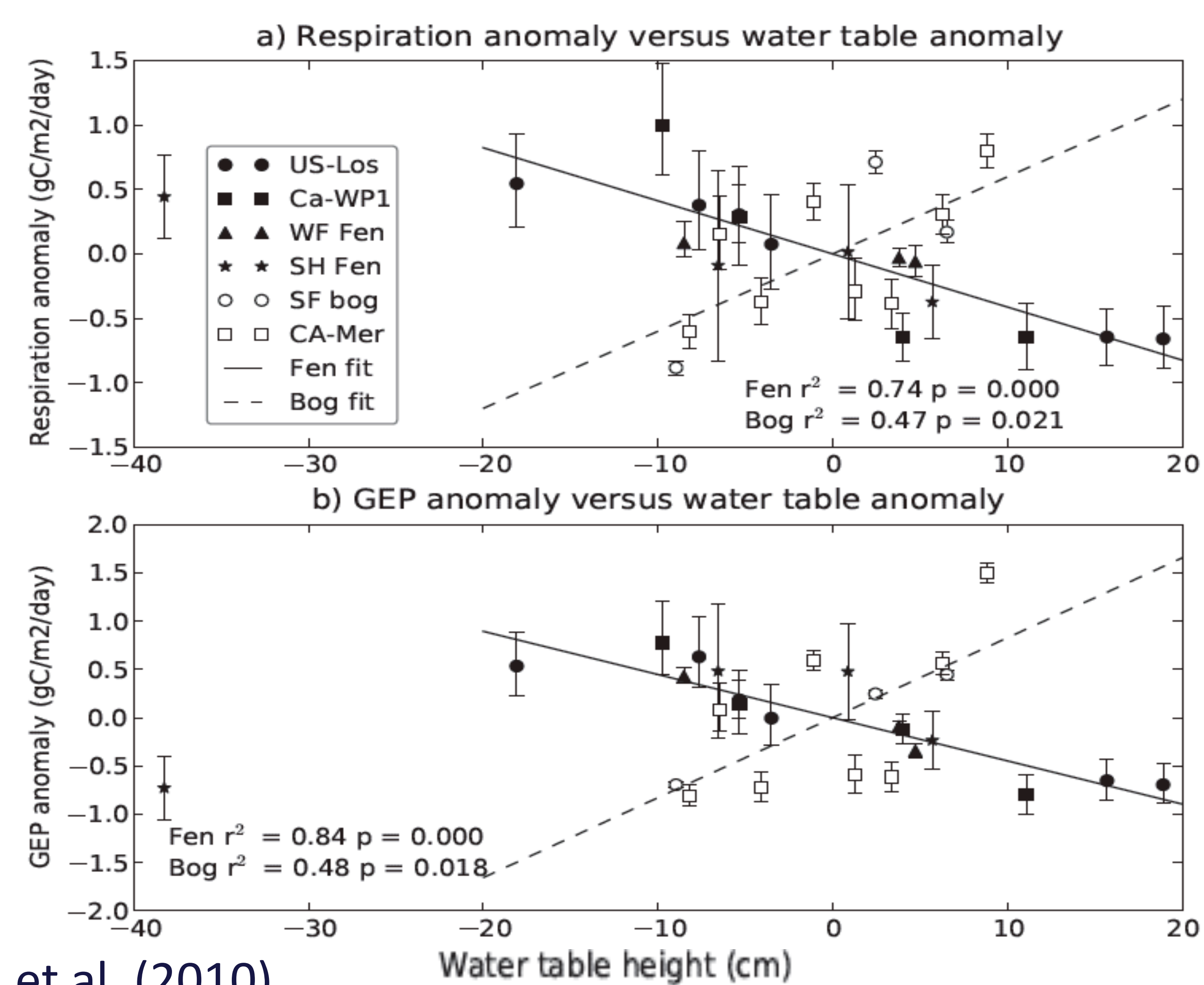
Hu et al. (2010)

Snow Water Drives Productivity



Hu et al. (2010)

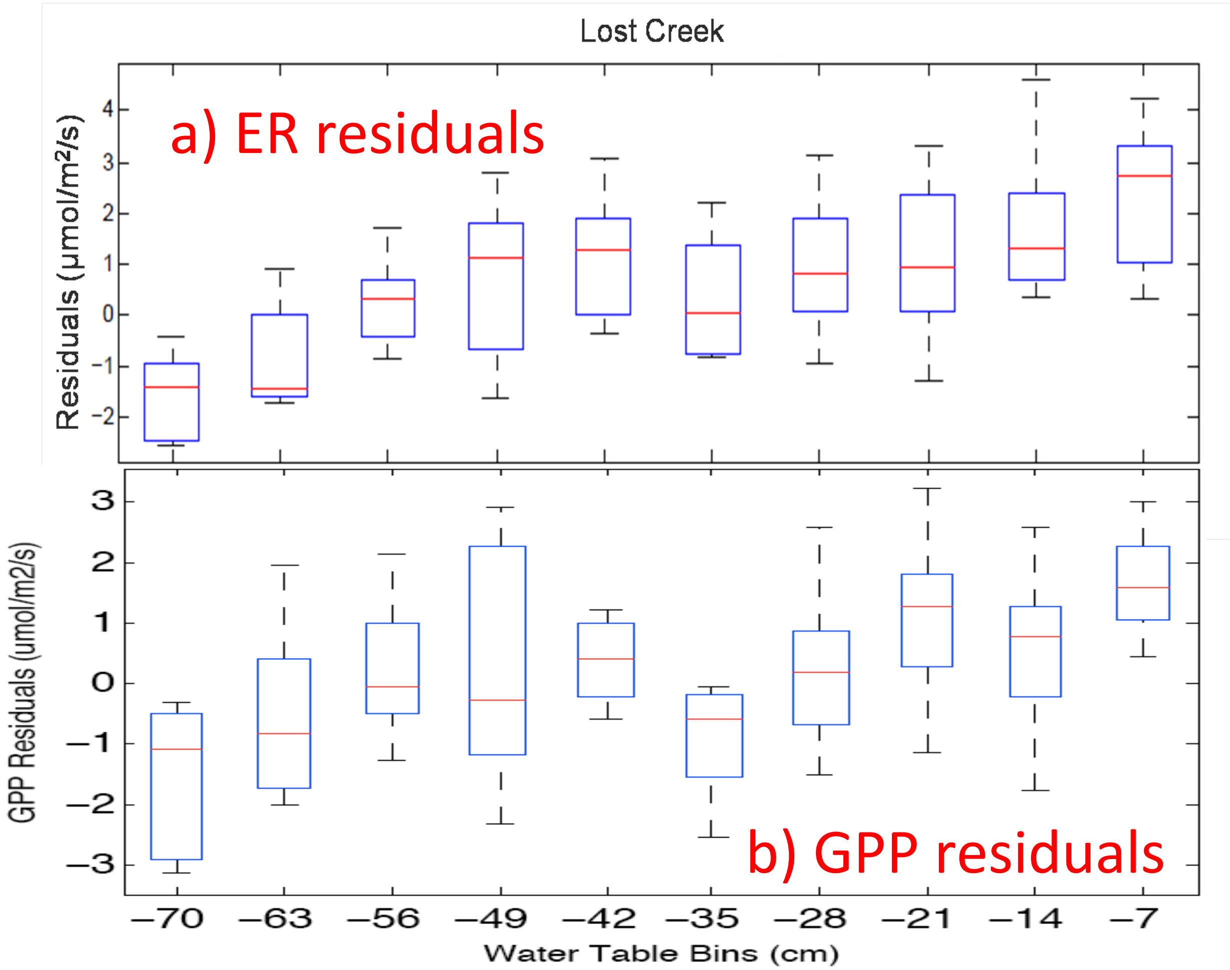
Speaking of Hydrology



Sulman et al. (2010)

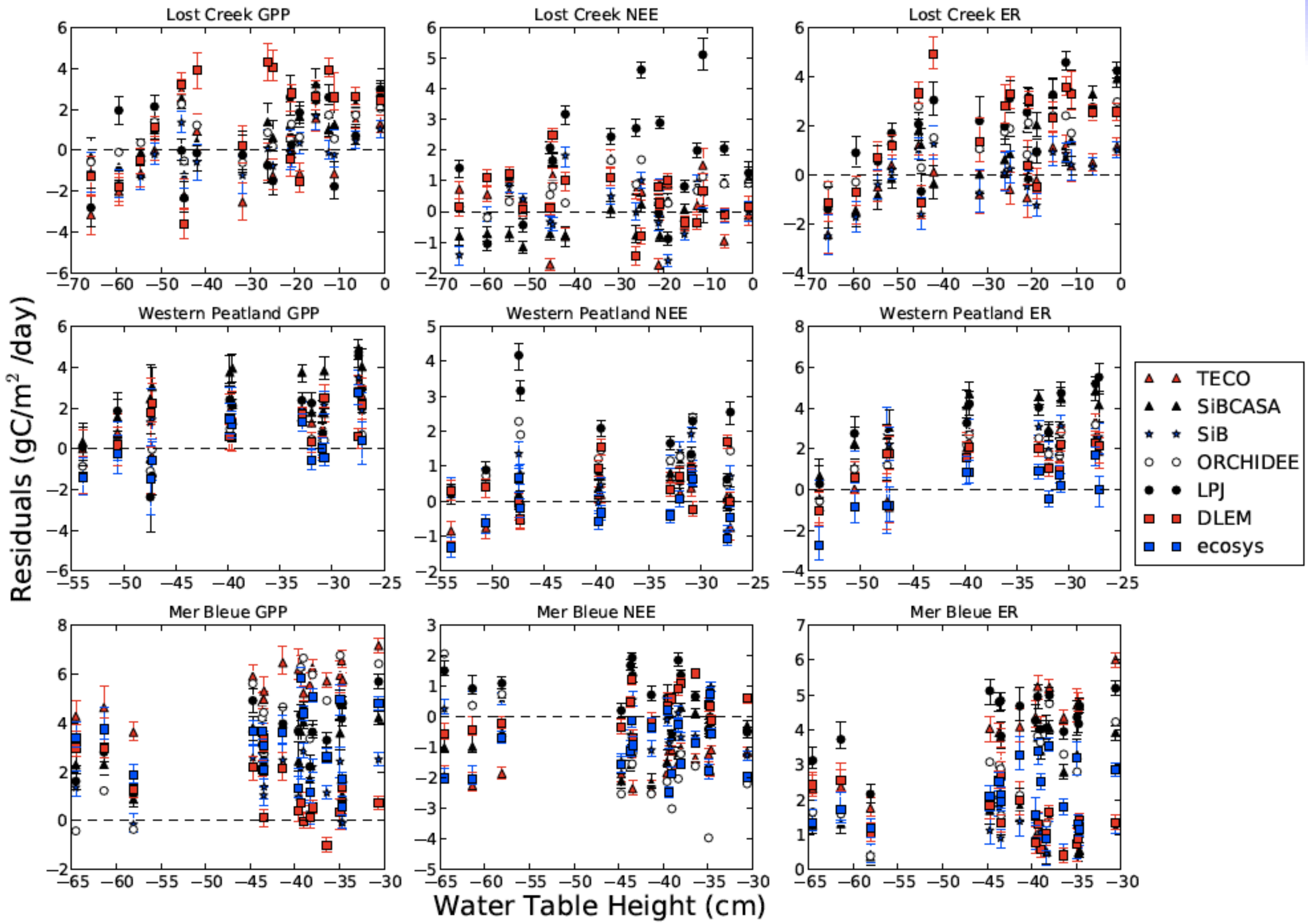
Do Models Get This?

- Six model intercomparison
  - Residuals = Modeled flux – Observed flux



Sulman et al., in prep

Water Table is a Critical Model Element

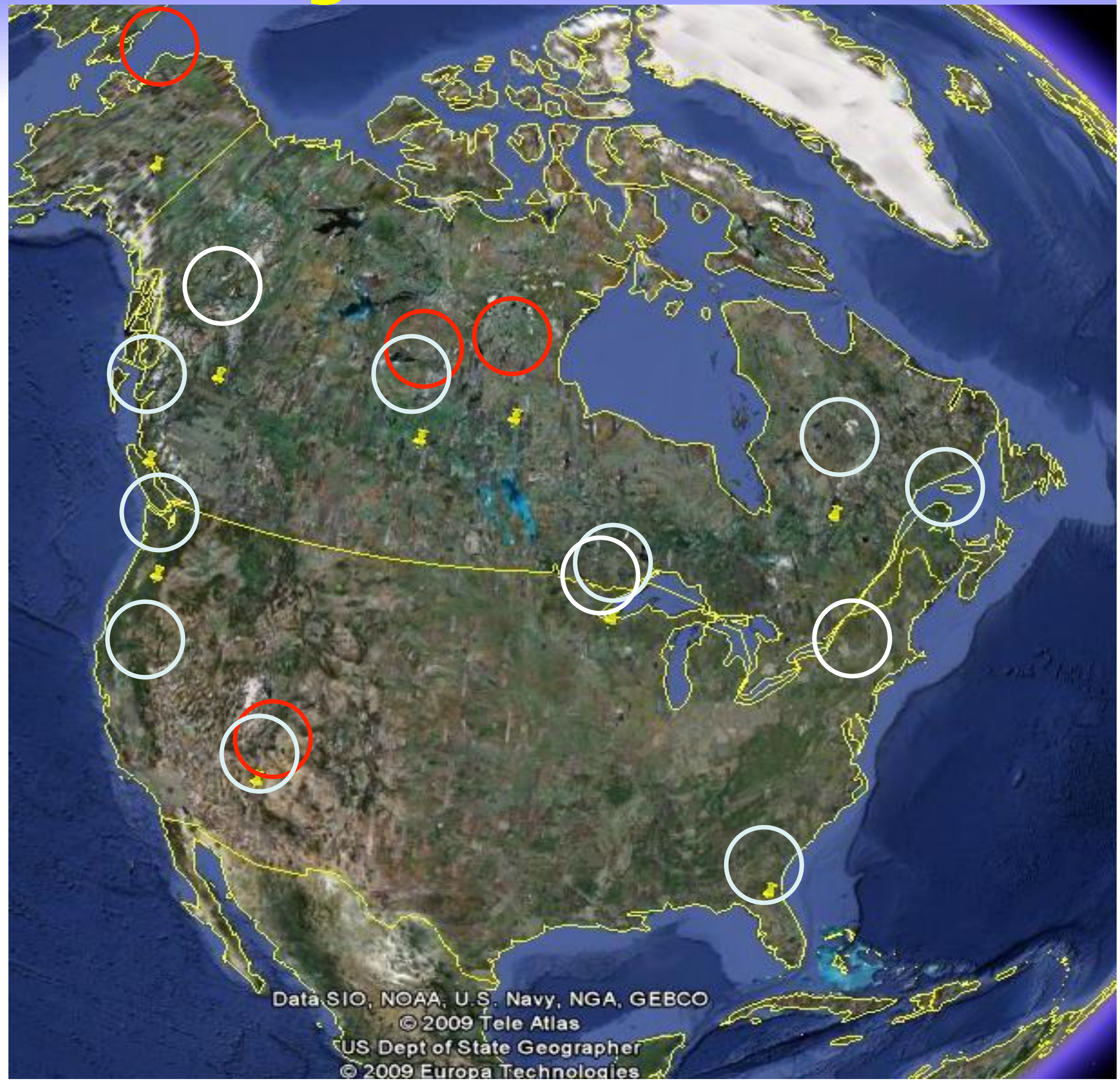


Sulman et al., in prep

What About Longer Time Scales?

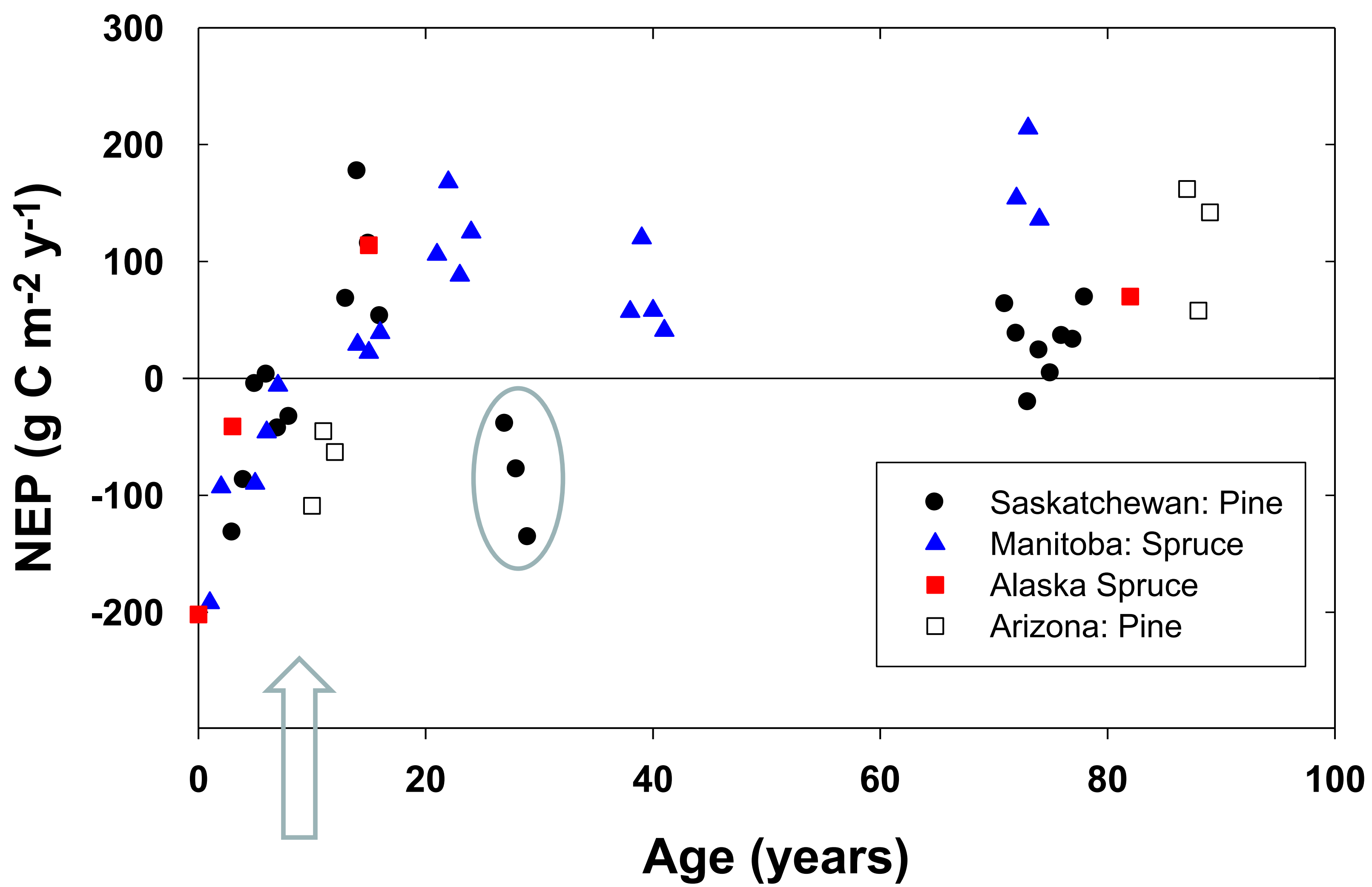
Disturbance Chronosequences with Annual NEP measured by eddy covariance

Fire = 4
Harvest = 7+
Insects = 3
Hurricane Wilma



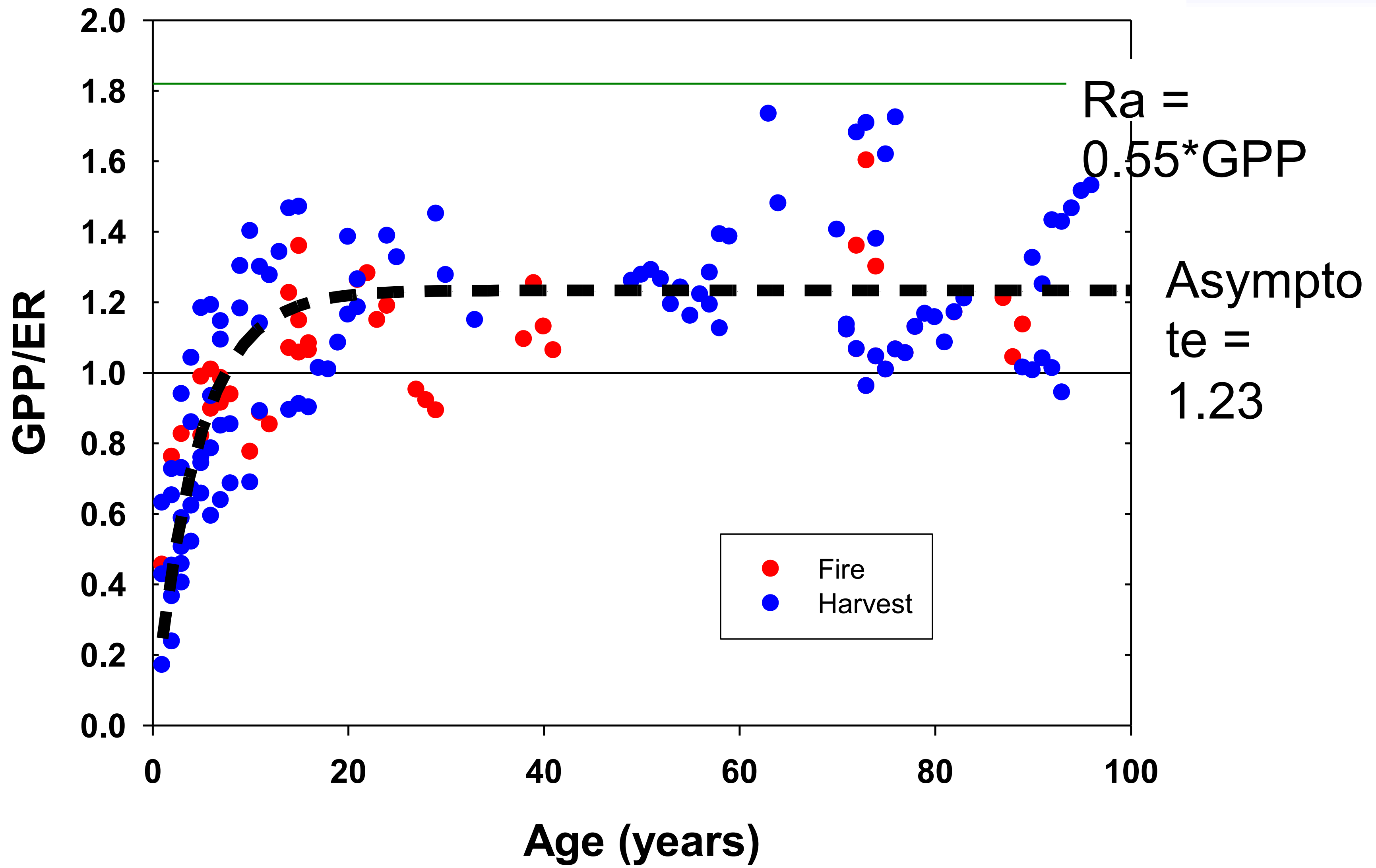
Amiro et al., 2010

Rapid Carbon Sink Recovery Post-Fire



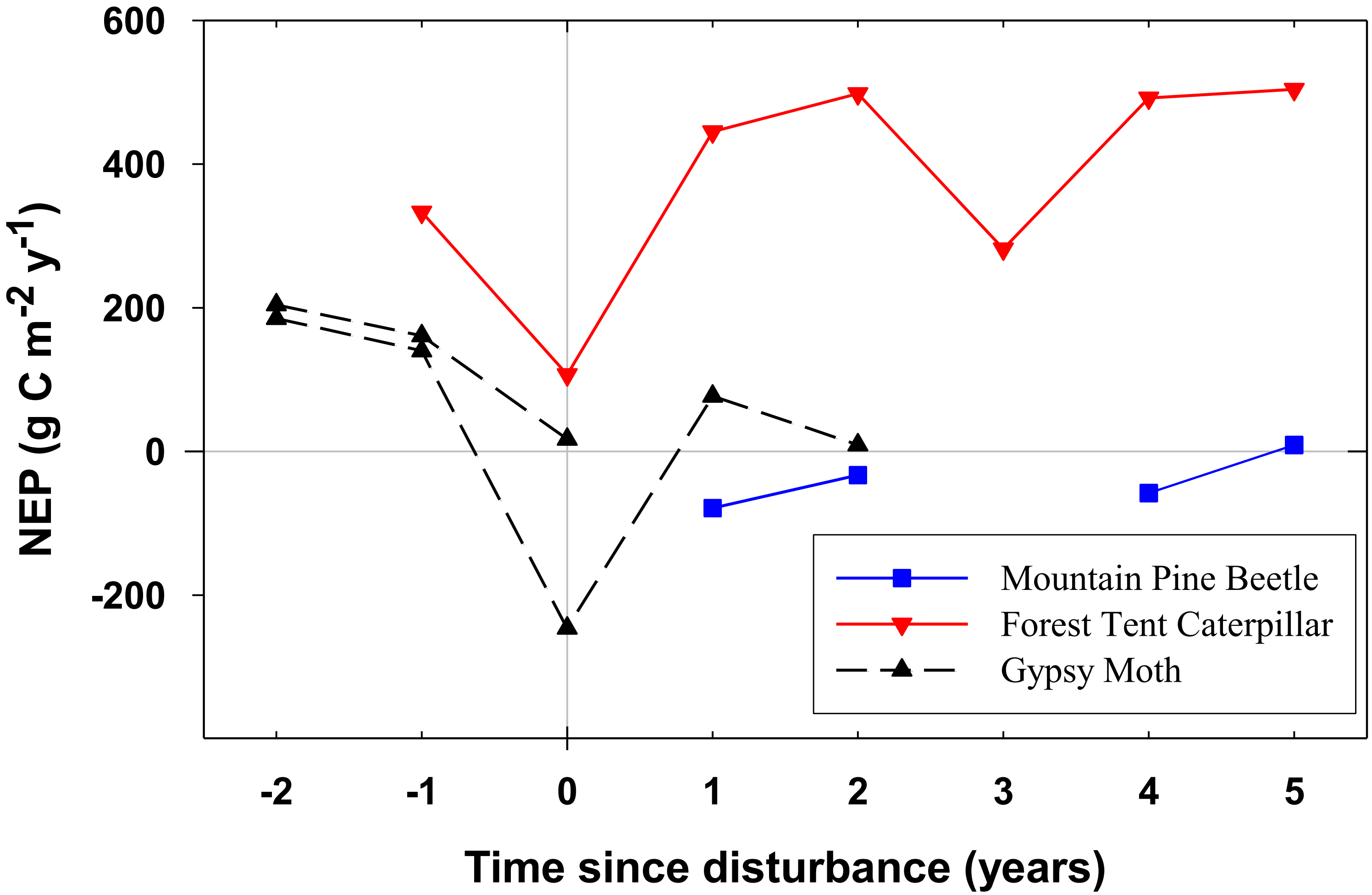
Amiro et al., 2010

Consistent Ratio of GPP/ER With Age



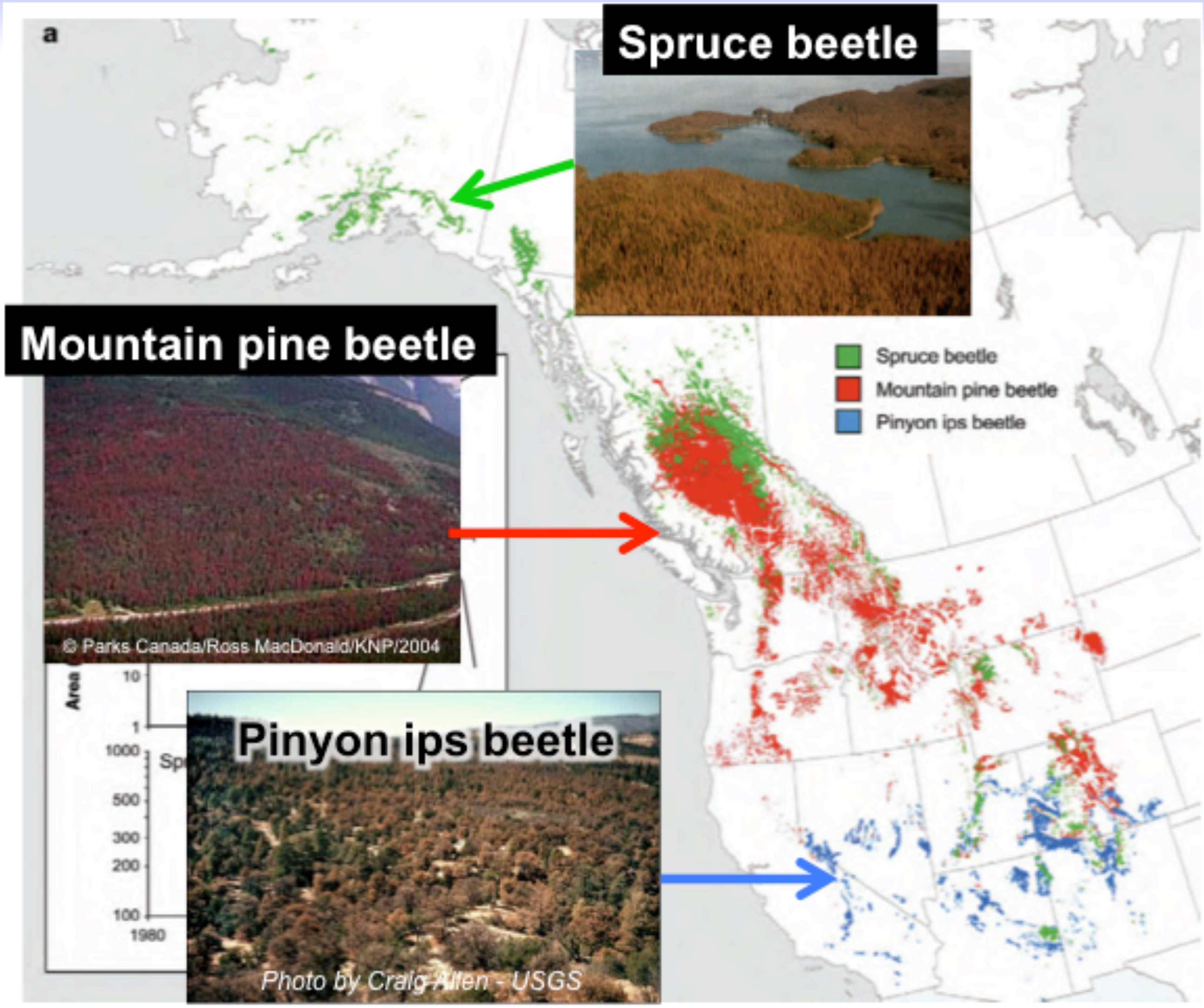
Amiro et al., 2010

Bugs Are Complicated!



Amiro et al., 2010

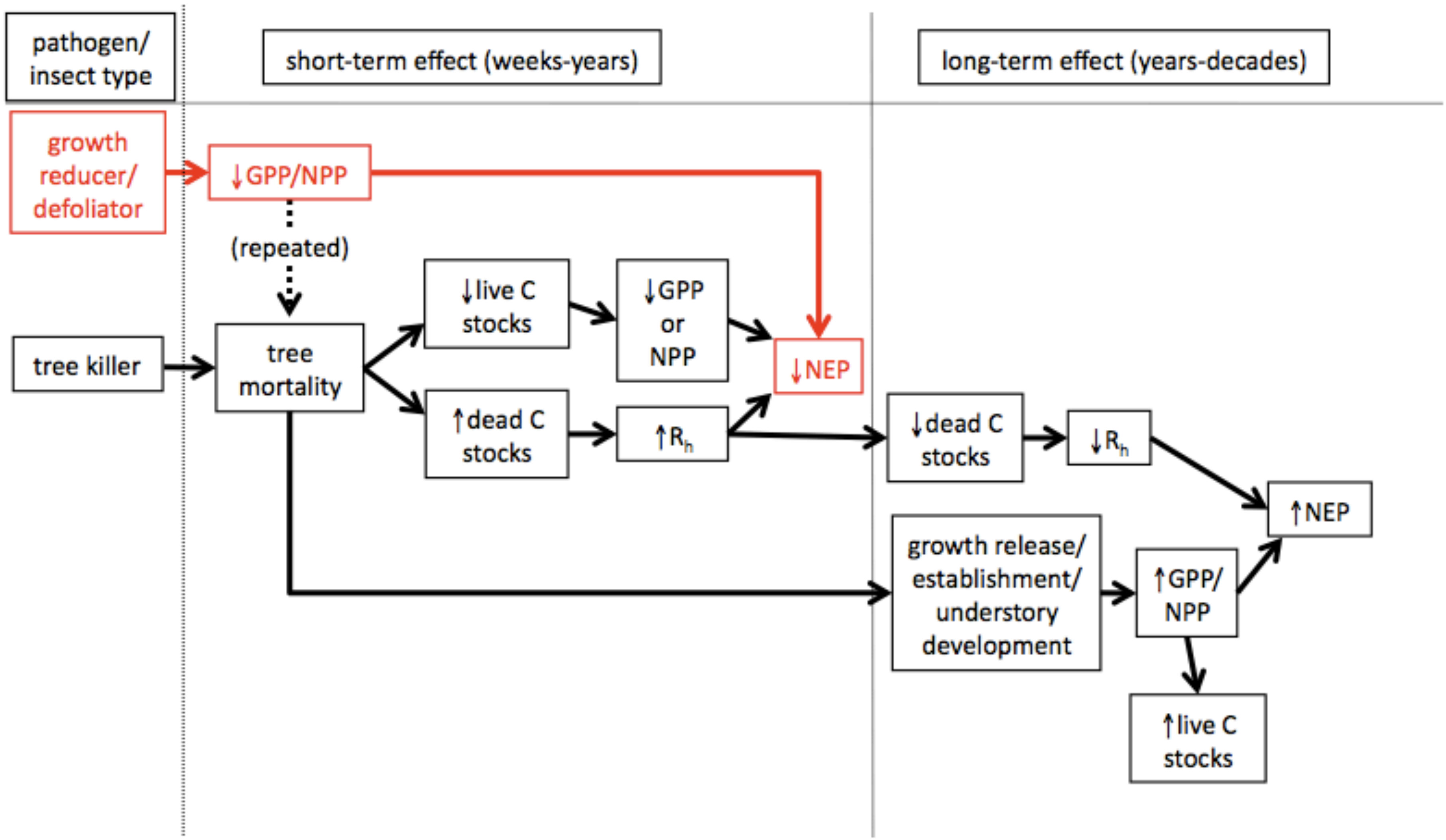
Extensive Bark Beetle Tree Mortality Suggests Large Impacts to C cycle…



Raffa et al., BioScience, 2008

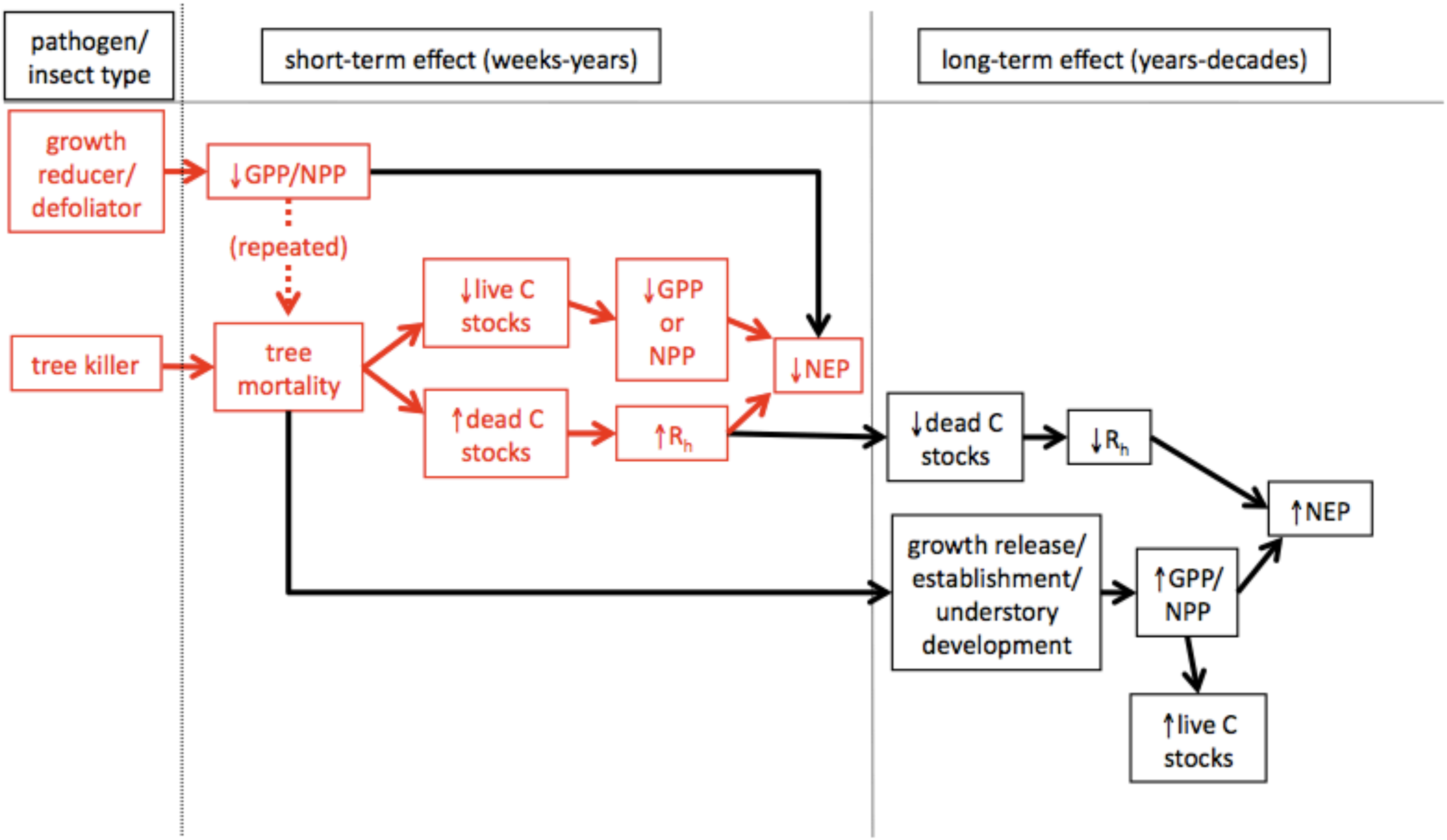
Growth Reduction Decreases NEP

Usually a temporary phenomenon



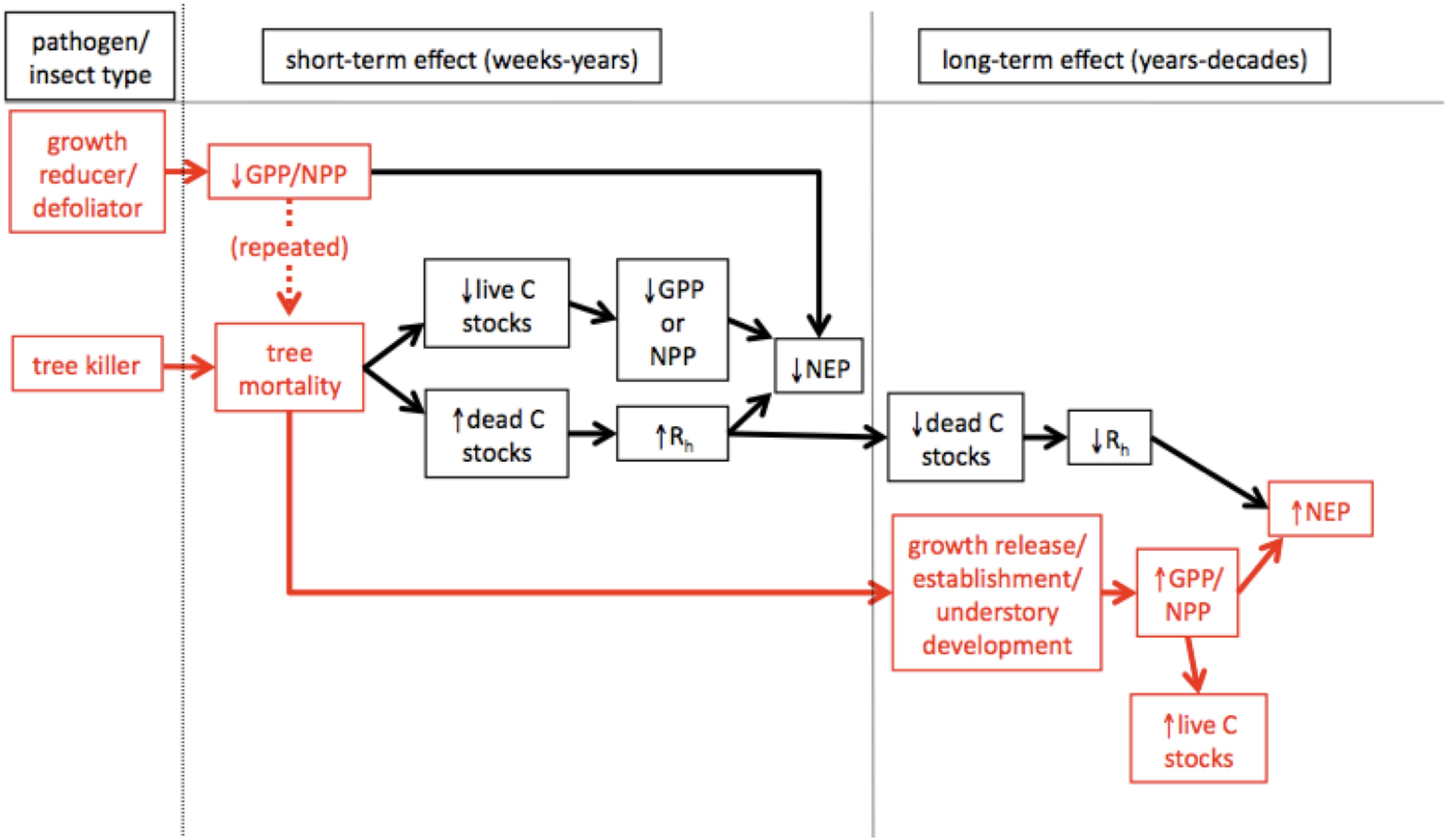
Hicke et al. in revision

Tree Mortality Decreases NEP



Hicke et al. in revision

Mortality Recovery Drives Flux Response



Hicke et al. in revision

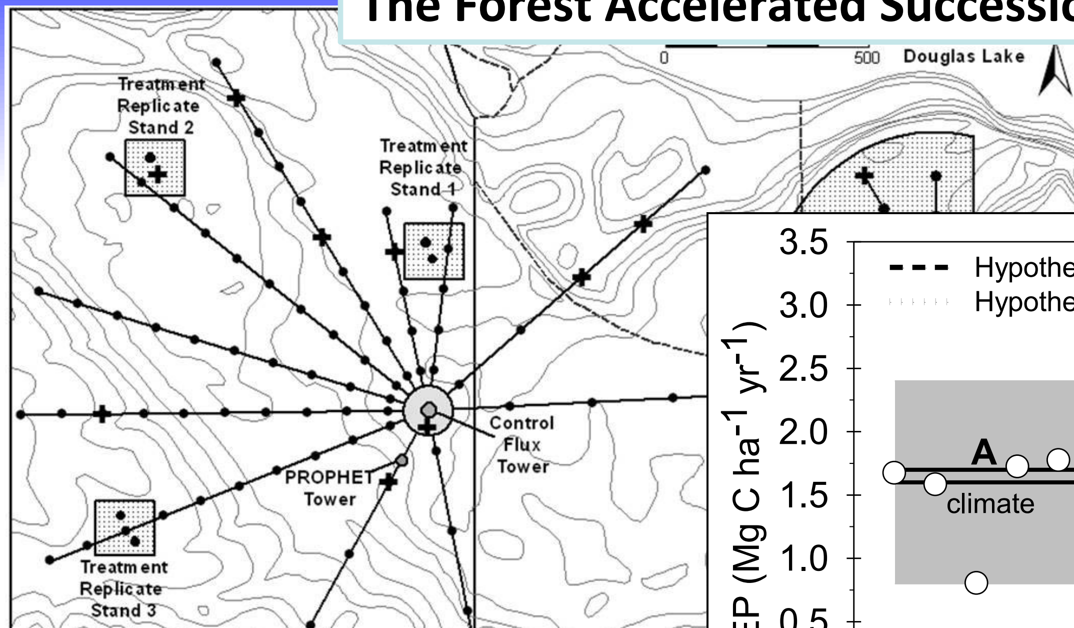
Where Do We Go From Here?

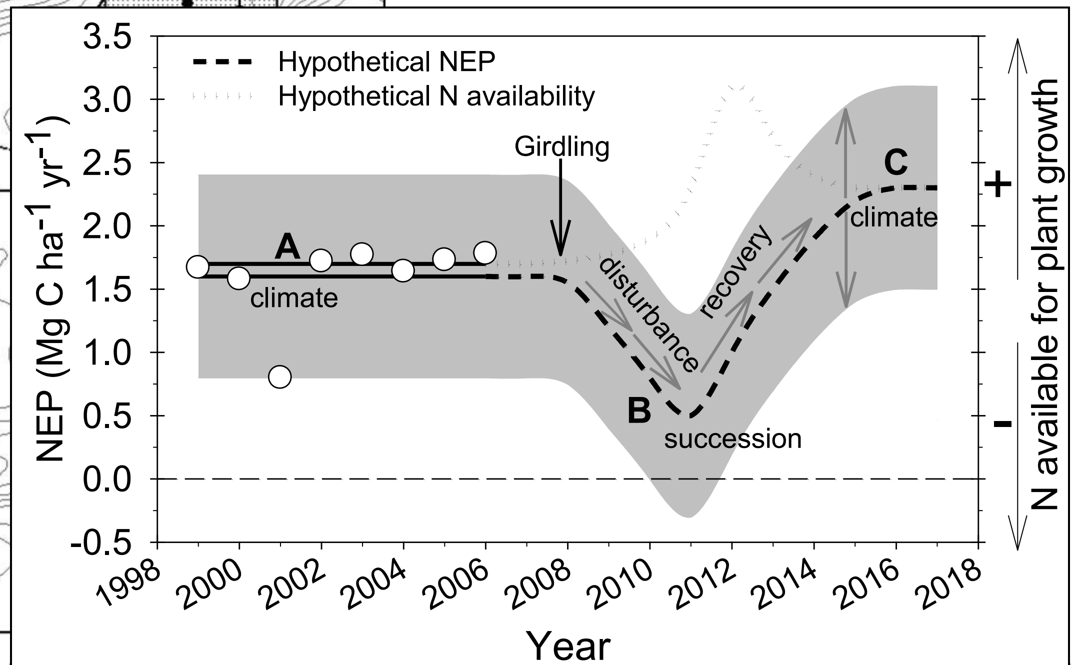
- More model intercomparison and benchmakring (MsTMIP, C-LAMB)
- Long-term carbon-cycle observatories (Fluxnet/Ameriflux, NEON, Inventory)
- Remote-sensing of disturbance (LEDAPS)
- Large and small scale manipulative experiments (FASET, ABoVE, MnSPRUCE)
- Theoretical advancement
- Vegetation dynamics in IPCC models: Phenology, large-scale episodic disturbance, succession, wetland hydrology

NEON, Inc.

Northern Rockies
12
Pacific Northwest
16
Great Basin
15
Pacific Southwest
17
Pacific Ocean
Northern Plains
9
Great Lakes
5
Northeast
1
Prairie Peninsula
6
Appalachians & Cumberland Plateau
7
Mid Atlantic
2
Atlantic Ocean
Central Plains
10
Southern Rockies & Colorado Plateau
13
Desert Southwest
14
Ozarks Complex
8
Southern Plains
11
Southeast
3
Gulf of Mexico
4
18
Tundra
Taiga
19
16
Pacific Tropical
20
Atlantic Neotropical
4
N
NEON Domains
NEON Candidate Aquatics
NEON Candidate Relocatables
NEON Candidate Coresite
1 Northeast
2 Mid Atlantic
3 Southeast
4 Atlantic Neotropical
5 Great Lakes
6 Prairie Peninsula
7 Appalachians/Cumberland Plateau
8 Ozarks Complex
9 Northern Plains
10 Central Plains
11 Southern Plains
12 Northern Rockies
13 Southern Rockies/Colorado Plateau
14 Desert Southwest
15 Great Basin
16 Pacific Northwest
17 Pacific Southwest
18 Tundra
19 Taiga
20 Pacific Tropical

The Forest Accelerated Succession ExperimenT (FASET)





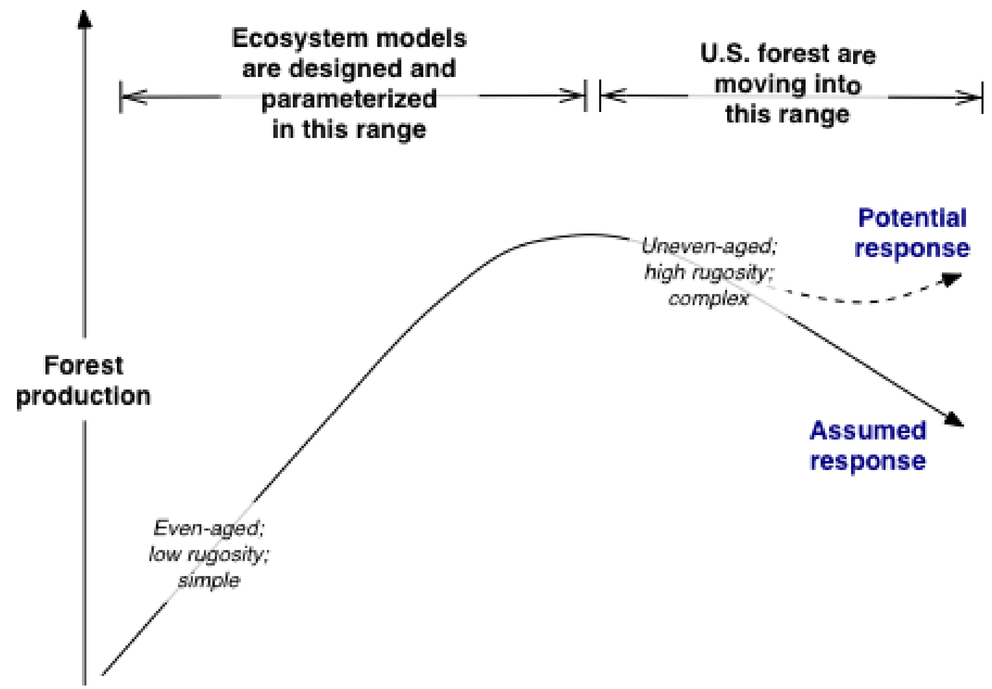
Conceptual model of NEP before, during, and following aspen and birch mortality. N availability will have an important effect on final NEP.

UMBS Forest Carbon Cycle Research Program

Courtesy of C. Gough, VCU

- ❑ Conventional theory suggests declining productivity and C storage in over-mature stands.
- ❑ Increasing biotic and structural complexity with age could alter this trajectory.

Figure 1. Conceptual diagram of forest age and production. Recent data have called into question the extent of productivity decline in mature-to-senescing stands. Most ecosystem models are poorly equipped to simulate forests in this older age range.



UMBS Forest Carbon Cycle Research Program

Courtesy of C. Gough, VCU

Theoretical Development

Climate change pressure

Changes in productivity:

- Warming in cold climates
- CO_2 fertilization
- Increased precipitation
- Increased nitrogen deposition
- Increased drought pressure

Changes in disturbance rates:

- Severe storms
- Logging and land use change
- Insect outbreaks
- Fire

Changes in decomposition rates:

- Warming leads to faster decomposition rates
- Increased drought pressure

Model parameter

Productivity multiplier

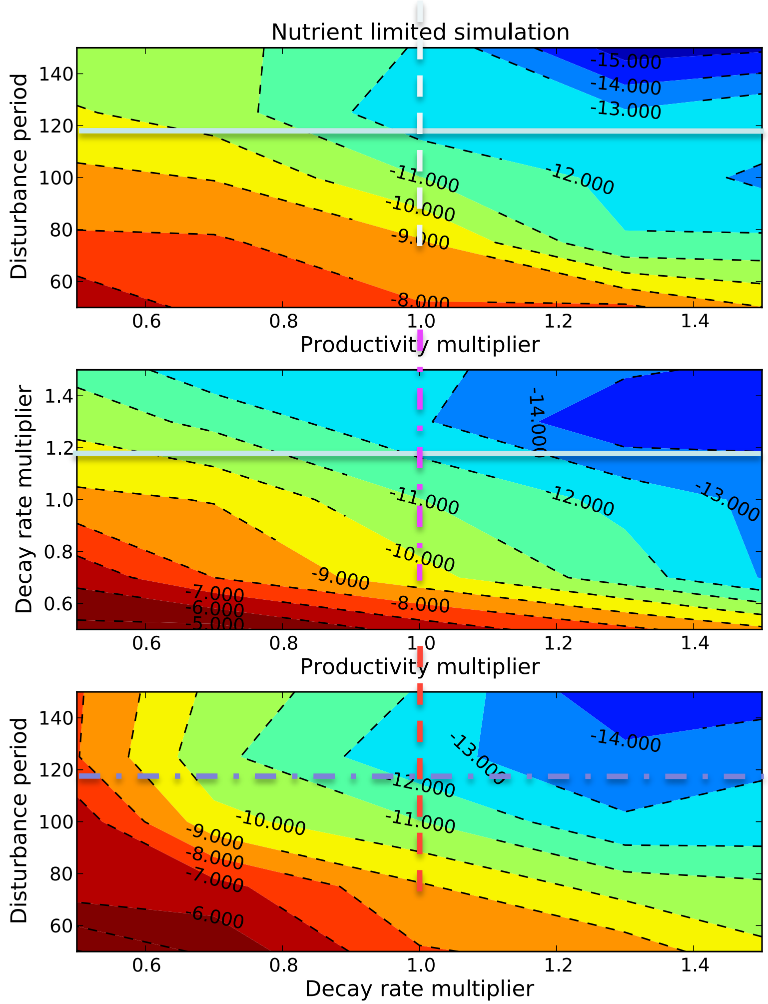
Disturbance interval

Decay rate multiplier

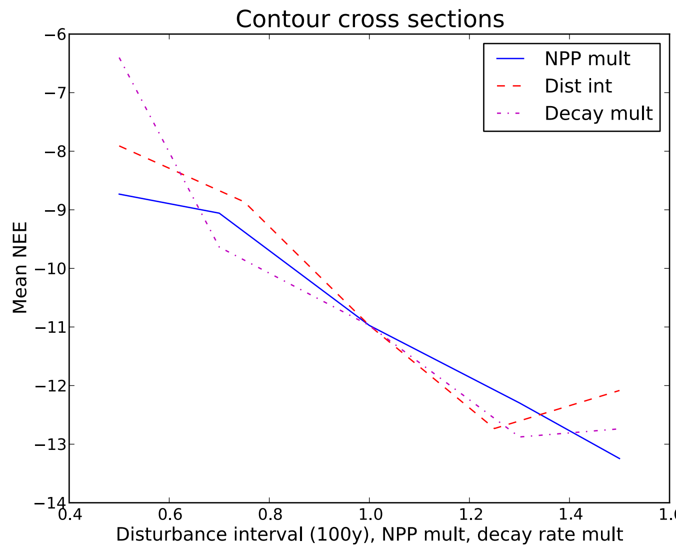
Sulman et al., in prep

Most Complex Model Has Similar Sensitivities to All Three Effects

Combination effects of three parameters:



- Increased decay rates cause higher carbon uptake
- CO_2 uptake has about the same sensitivity to changes in all three parameters

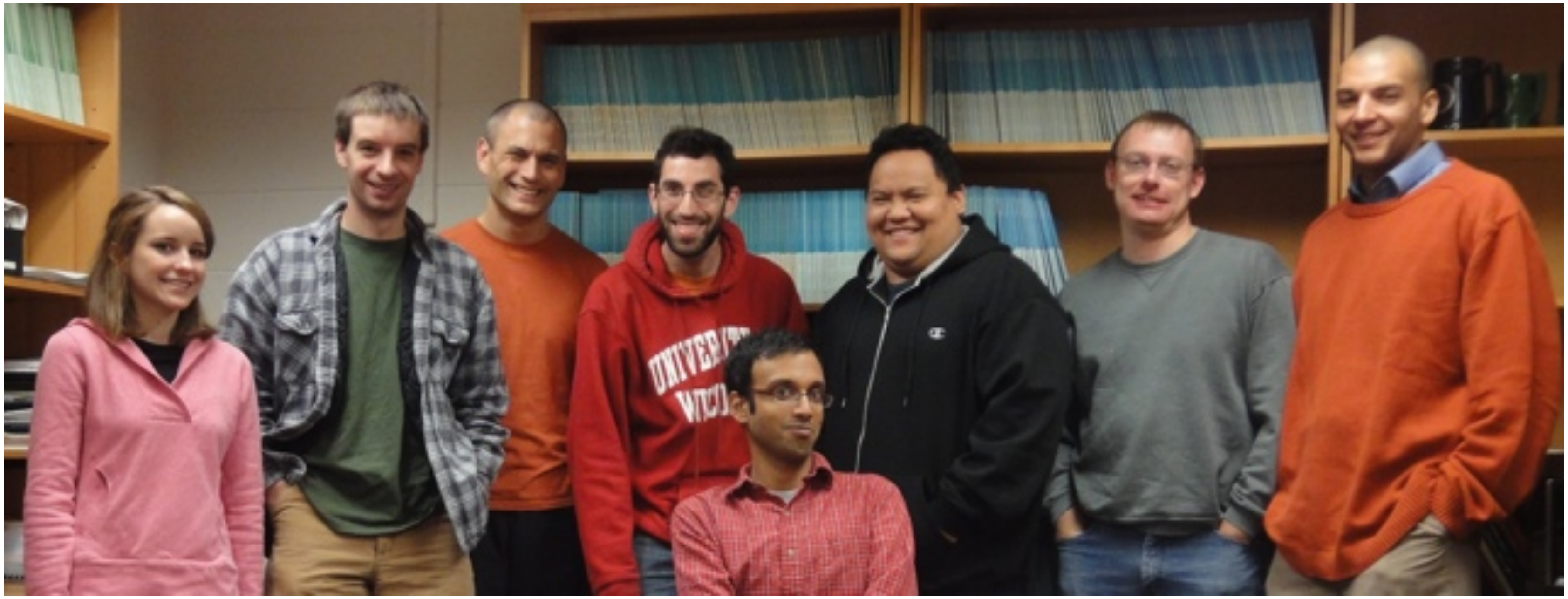


Conclusions

- Multi-year multi-site flux-tower observations provide evidence for mechanisms that link phenology, hydrology, and biotic disturbance to carbon cycle
- Ecosystem models need continued "acid tests" to constrain and select optimal model structure and parameters
- Things I didn't talk about:
  - Plant and microbial adaptation
  - Invasive species, herbivory, population dynamics
  - Rapid climate change
  - Nutrient cycling
  - Aquatic-terrestrial linkages
  - Coupled water/carbon cycle and boundary layer feedbacks
  - Lots of things!

Thanks!

- Desai Ecometeorology Lab (flux.aos.wisc.edu):



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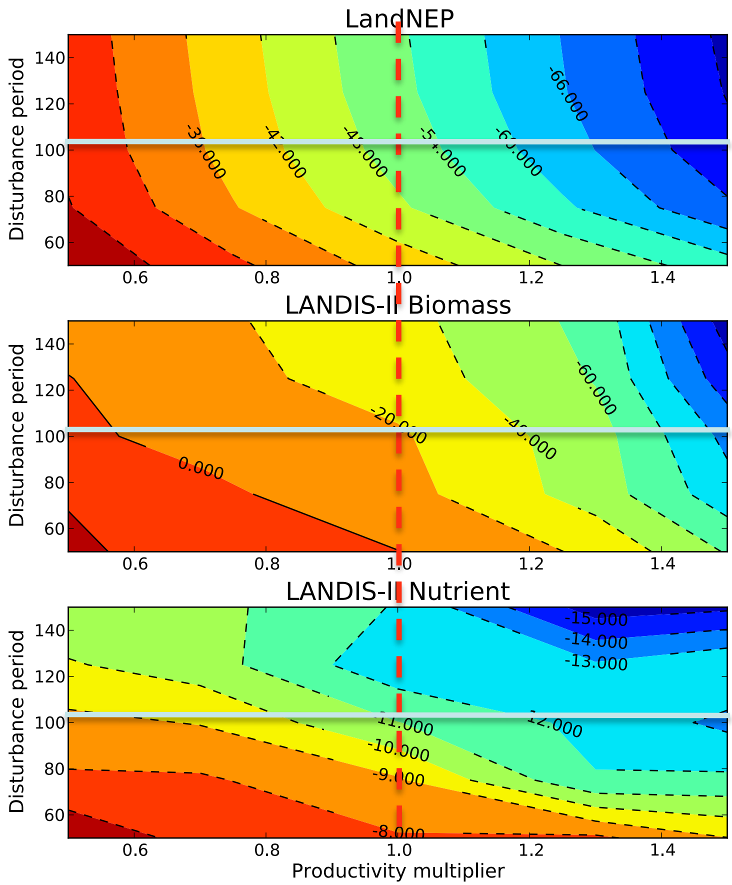
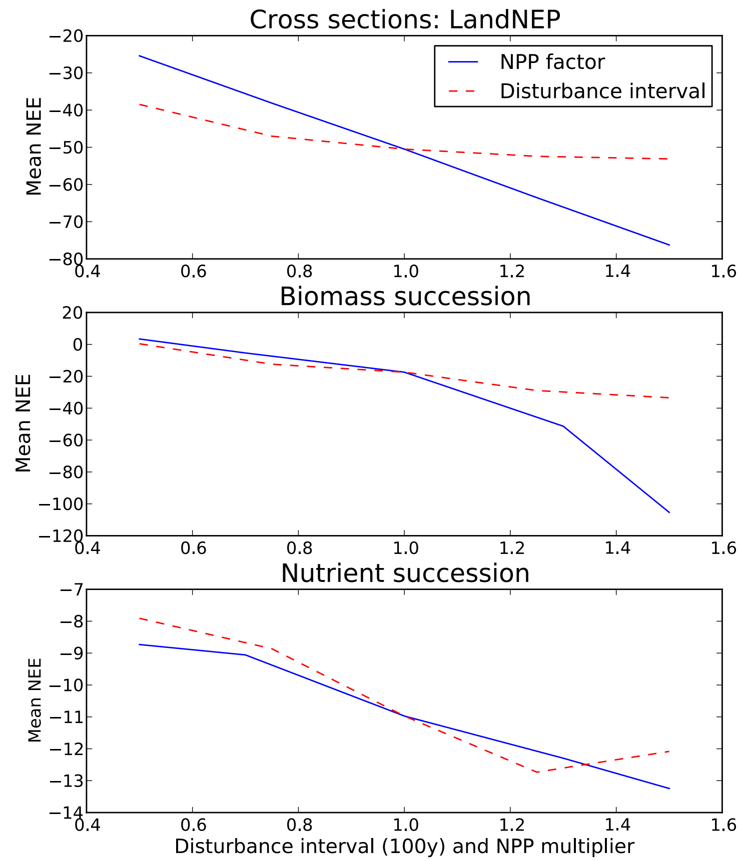
Model Complexity Drives Disturbance Sensitivity

200-year modeled mean NEE for different parameter combinations



Blue colors = higher C uptake

Ratios of sensitivity to the two parameters



Negative numbers = C uptake